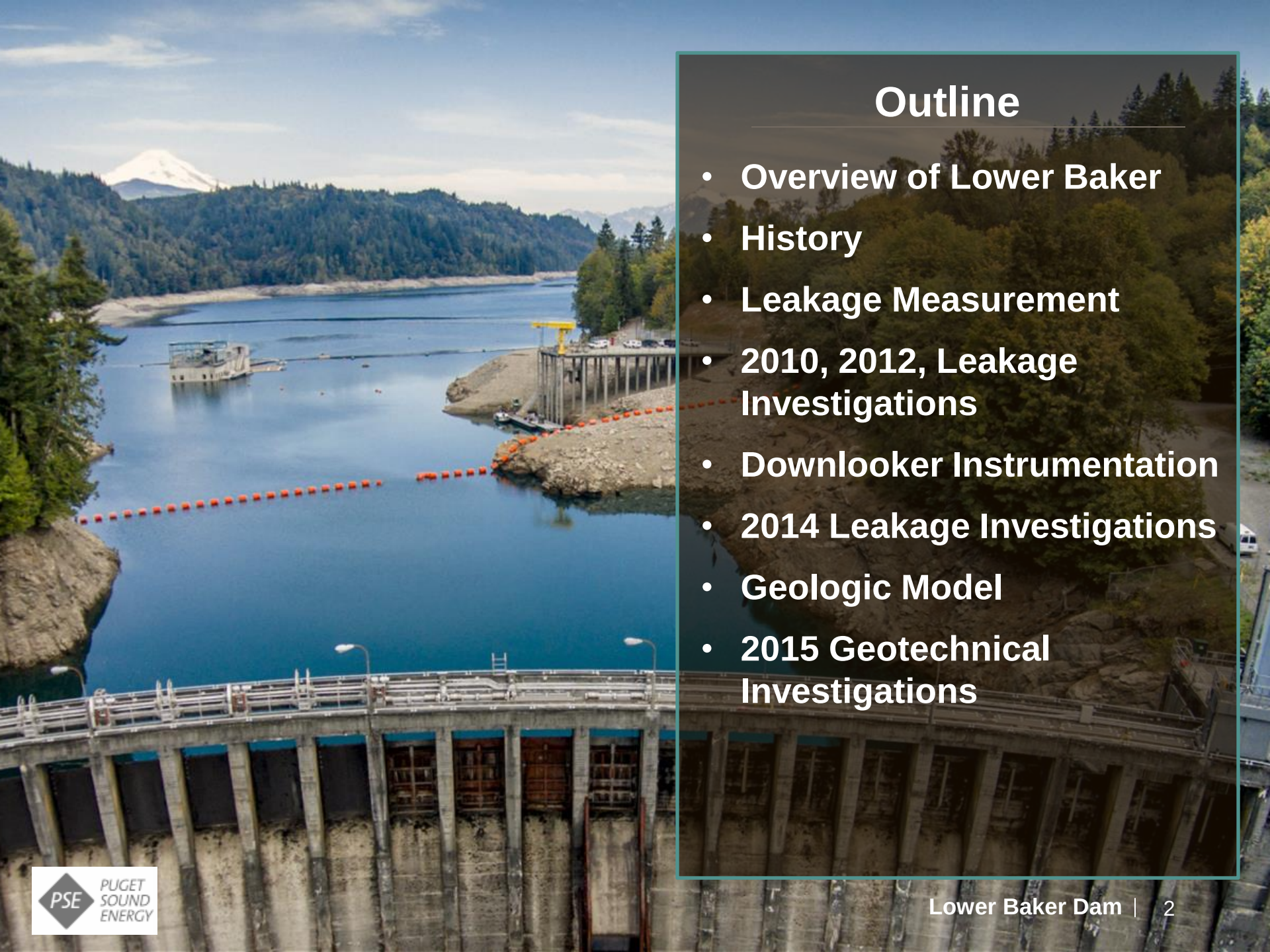
Lower Baker Dam Leakage Investigations

Jim Sammet, PE
Lower Baker Dam Capital Program Manager



Outline

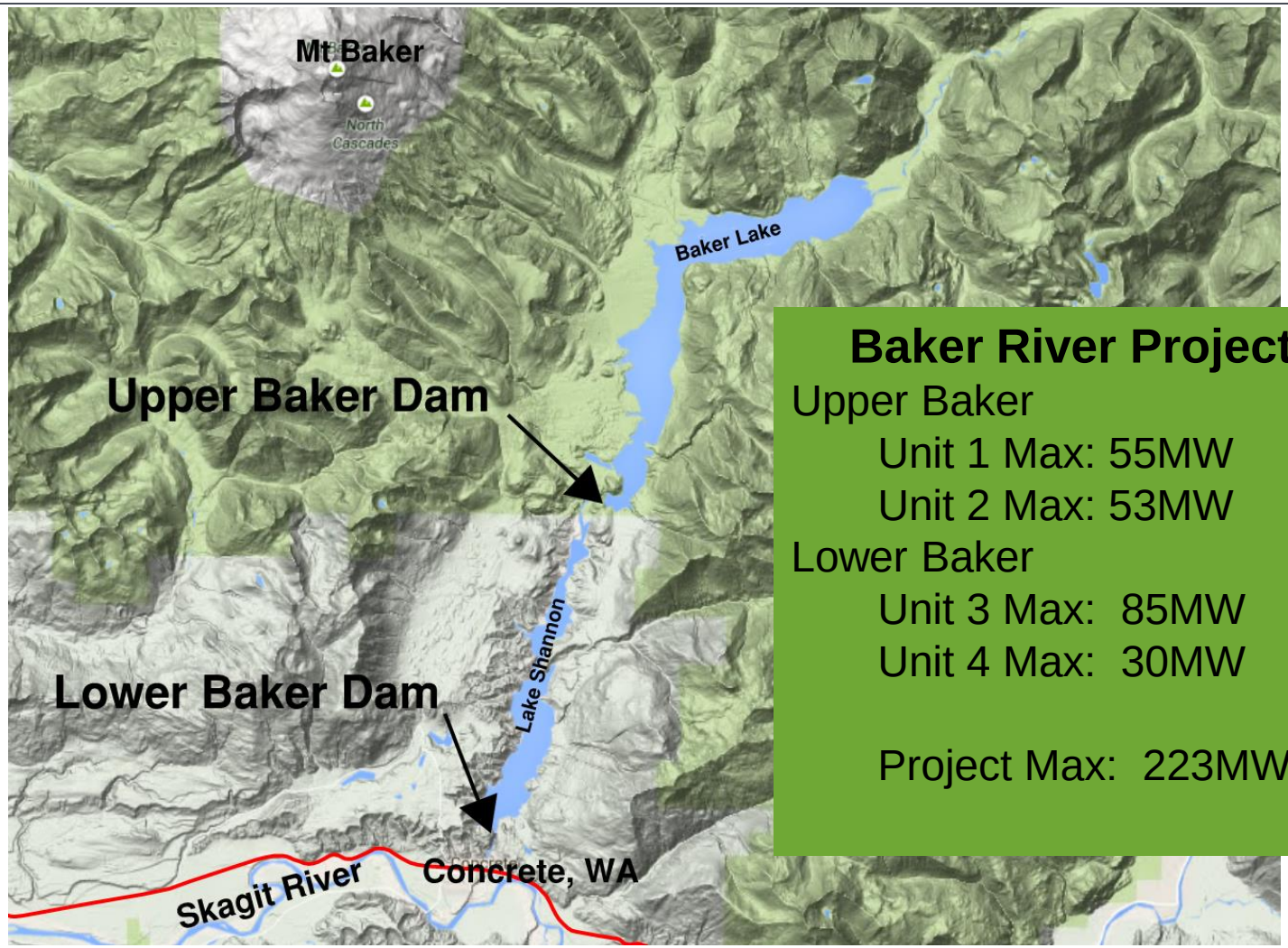
- Overview of Lower Baker
- History
- Leakage Measurement
- 2010, 2012, Leakage Investigations
- Downlooker Instrumentation
- 2014 Leakage Investigations
- Geologic Model
- 2015 Geotechnical Investigations

PSE PUGET SOUND ENERGY

Baker River Hydro Project Location

PUGET SOUND ENERGY

Baker River Hydro Project



Baker River Project

Upper Baker
- Unit 1 Max: 55MW
- Unit 2 Max: 53MW

Lower Baker
- Unit 3 Max: 85MW
- Unit 4 Max: 30MW

Project Max: 223MW

PUGET SOUND ENERGY

Lower Baker Dam Overview

- Concrete Thick Arch Dam
- Base is 160 ft. thick.
- Height = 285 ft.
- Span = 405 ft.
- Spillway Section = 275 ft.

PSE PUGET SOUND ENERGY

Lower Baker Dam Overview

- Length = 7 miles.
- Area = 2,300 acres
- Drainage Area = 300 sq. mi
- Total Storage is 132,000 ac-ft with active storage of over 29,000 ac-ft.
- Named for W.D. Shannon, Chief Engineer for original dam construction

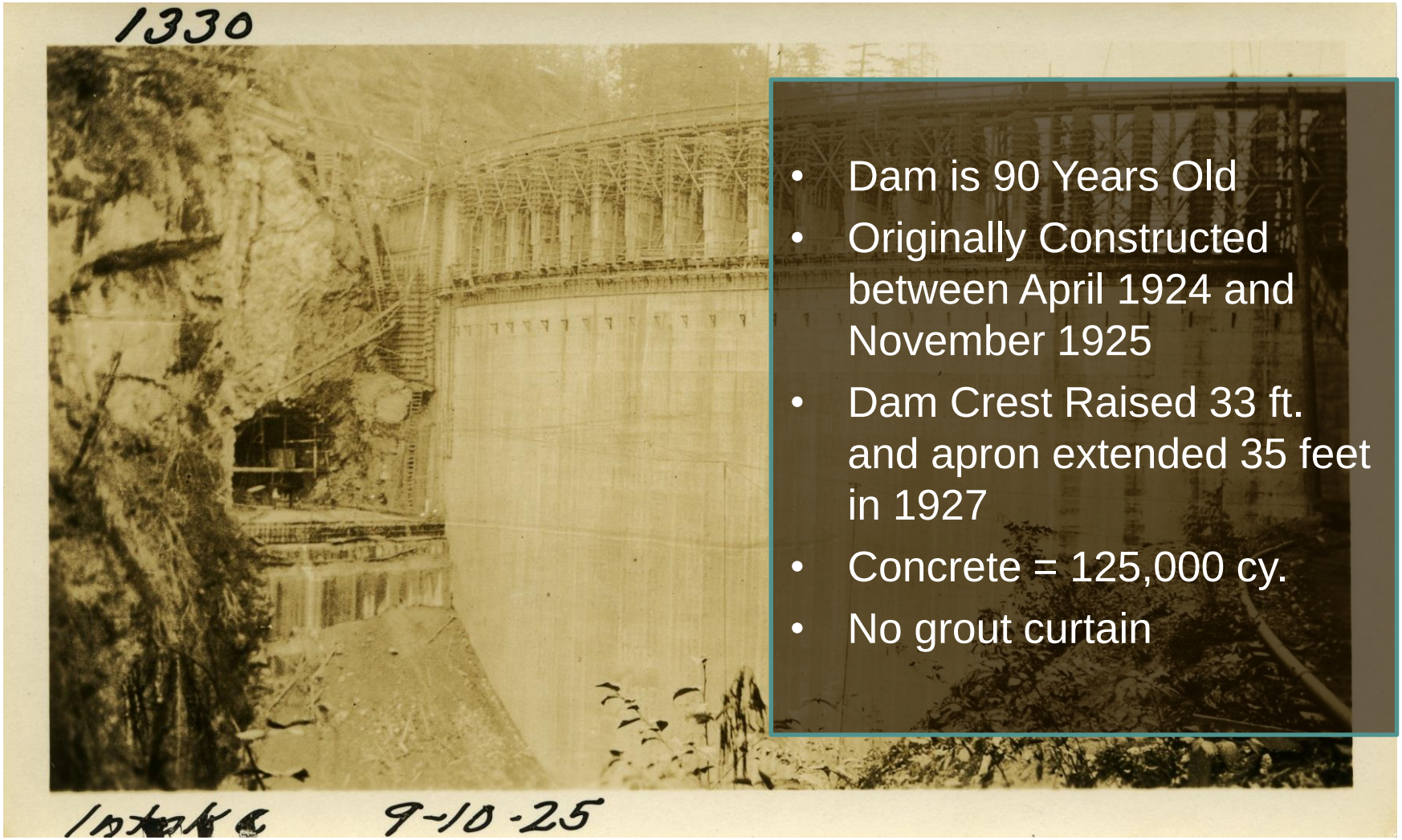
PUGET SOUND ENERGY

Lower Baker Dam Overview

- 23 operating gates
- 13 gates operated by 3 types of automated hoist operators
- 10 gates operated manually with a gate car
- Separate intake structure with trash racks and wheel head gates
- 65 ft. drawdown by generation or bypass valve
- No low level outlet

PUGET SOUND ENERGY

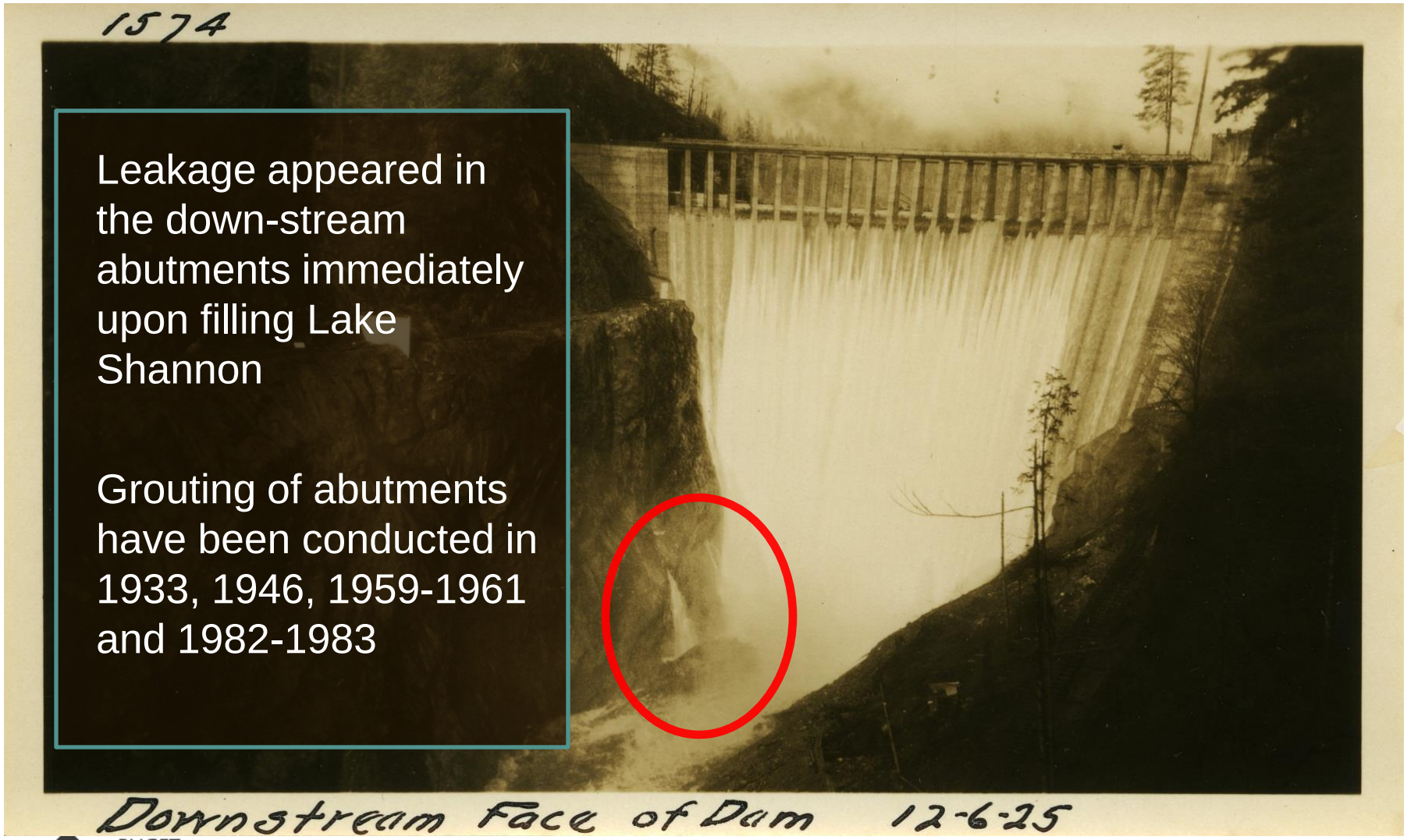
Lower Baker Dam History



- Dam is 90 Years Old
- Originally Constructed between April 1924 and November 1925
- Dam Crest Raised 33 ft. and apron extended 35 feet in 1927
- Concrete = 125,000 cy.
- No grout curtain

PUGET SOUND ENERGY

Lower Baker Dam History



Leakage appeared in the down-stream abutments immediately upon filling Lake Shannon

Grouting of abutments have been conducted in 1933, 1946, 1959-1961 and 1982-1983

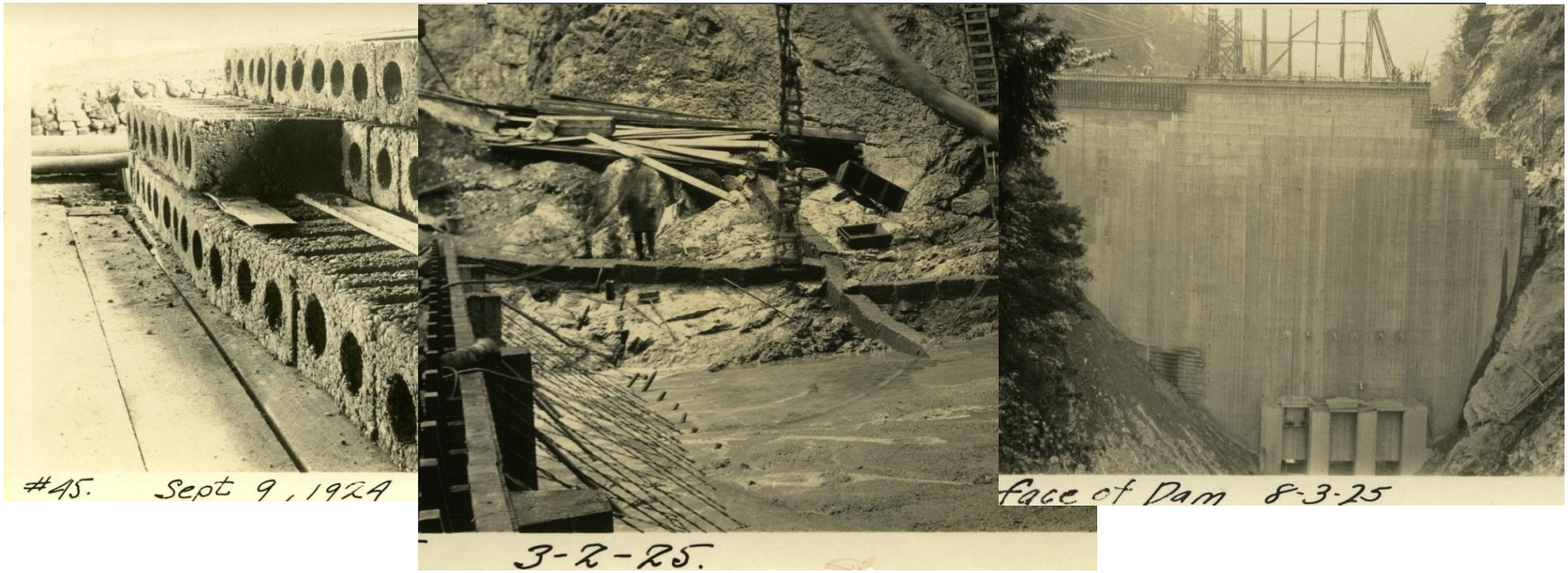
PSE PUGET SOUND ENERGY

Lower Baker Dam History

- In 1965 the original powerhouse was destroyed by a landslide.
- Original record drawings stored in powerhouse were also destroyed.
- The result is we know little about the design and construction of the dam

PUGET SOUND ENERGY

Lower Baker Dam History



Through some luck;

- PSE has obtained approximately 1500 high quality photographs taken during the original construction of the dam.

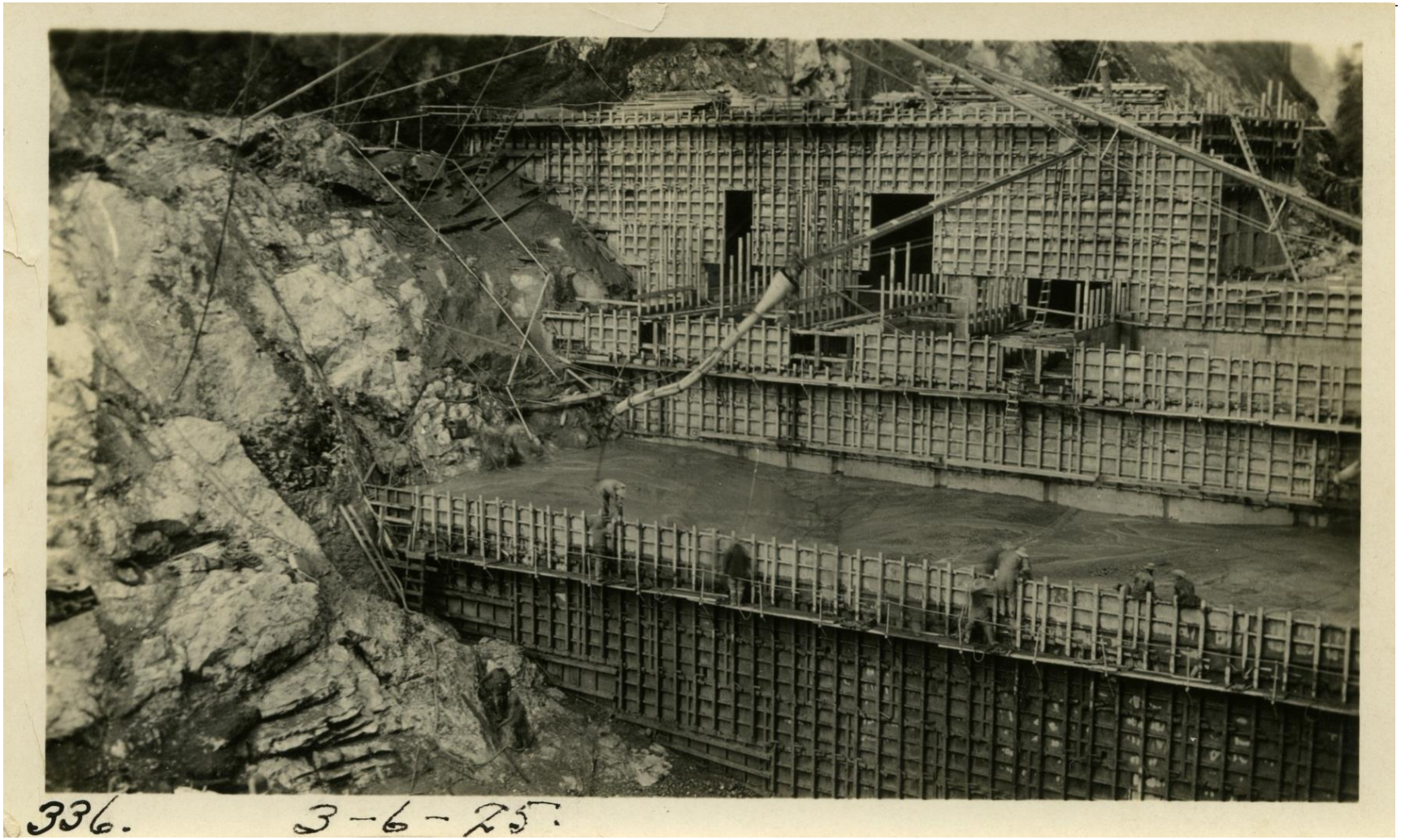
PUGET SOUND ENERGY

Lower Baker Dam History

Use of cycloptic concrete of “dead heads” in dam foundation

PUGET SOUND ENERGY

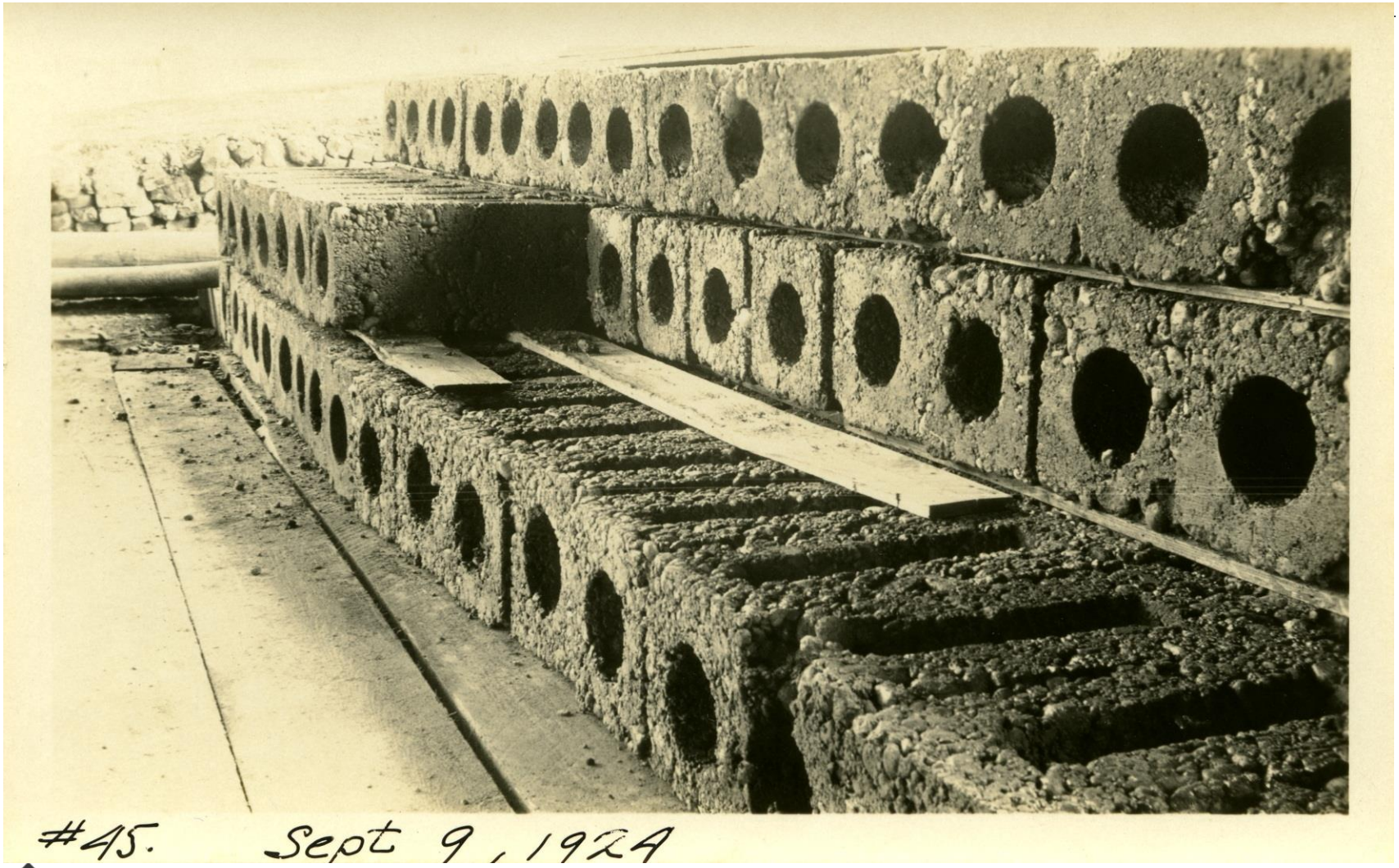
Lower Baker Dam History



Construction Sequence of Concrete lifts and blocks

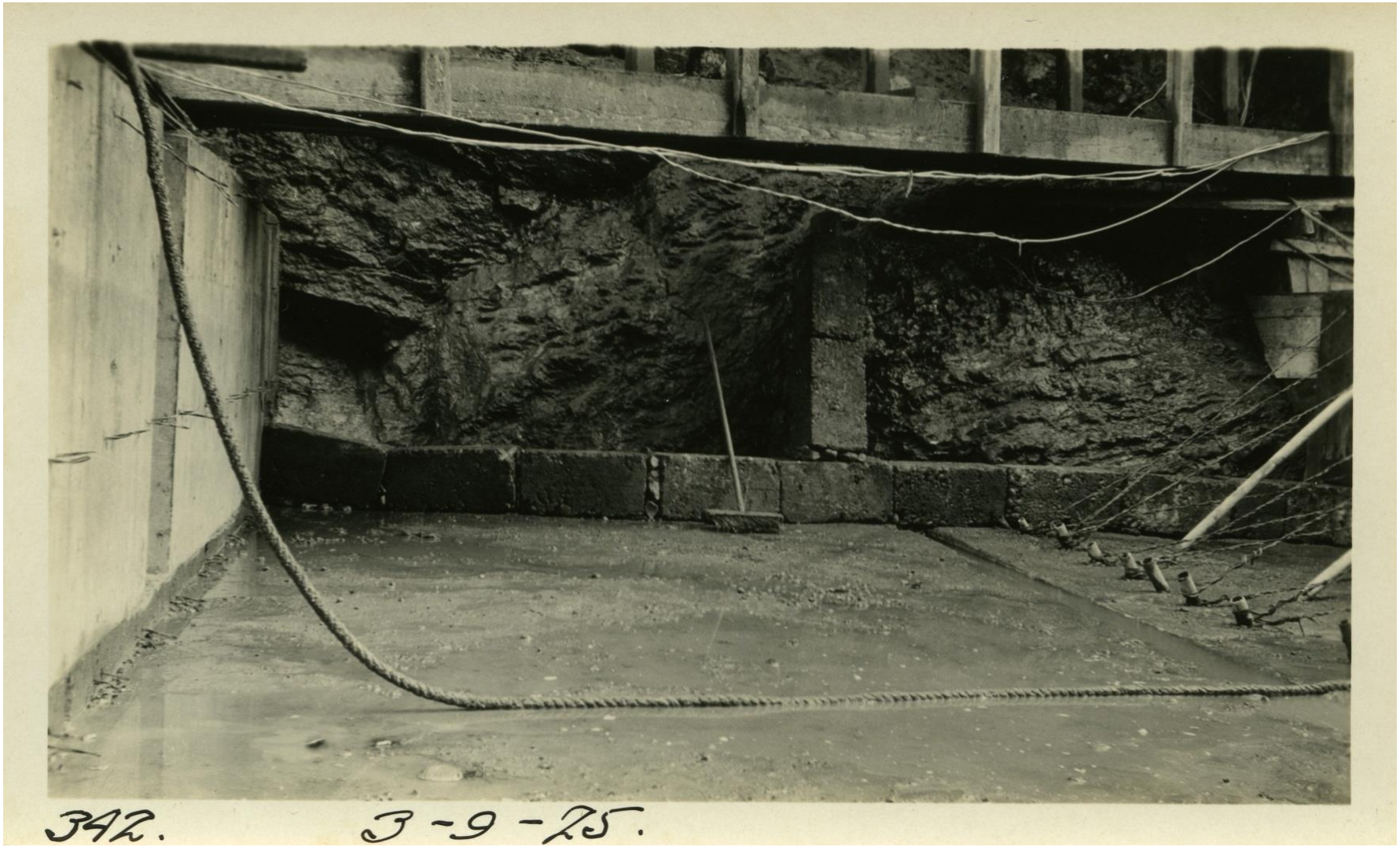
PUGET SOUND ENERGY

Lower Baker Dam History



PUGET SOUND ENERGY

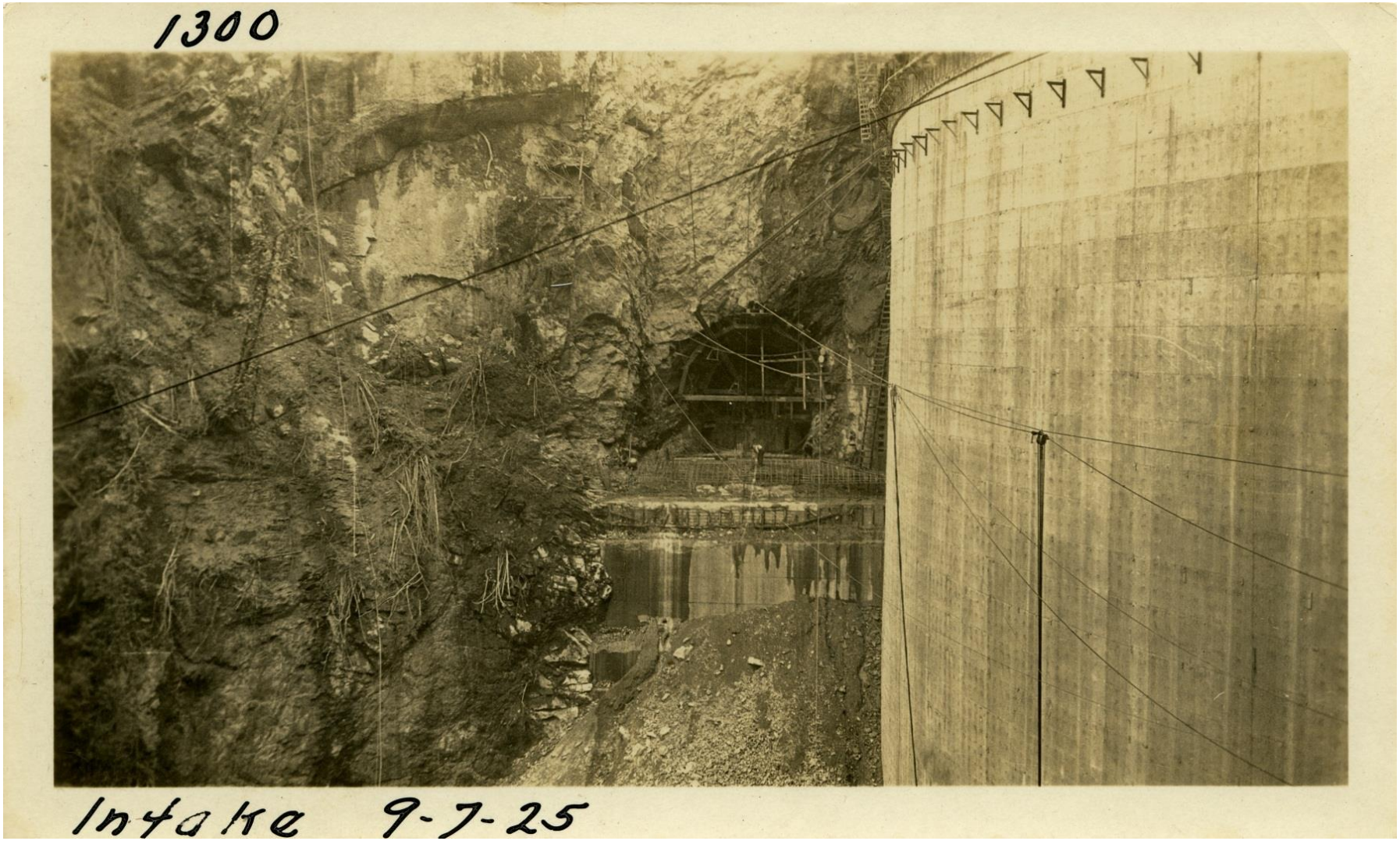
Lower Baker Dam History



Placement of drainage tile along abutment face

PUGET SOUND ENERGY

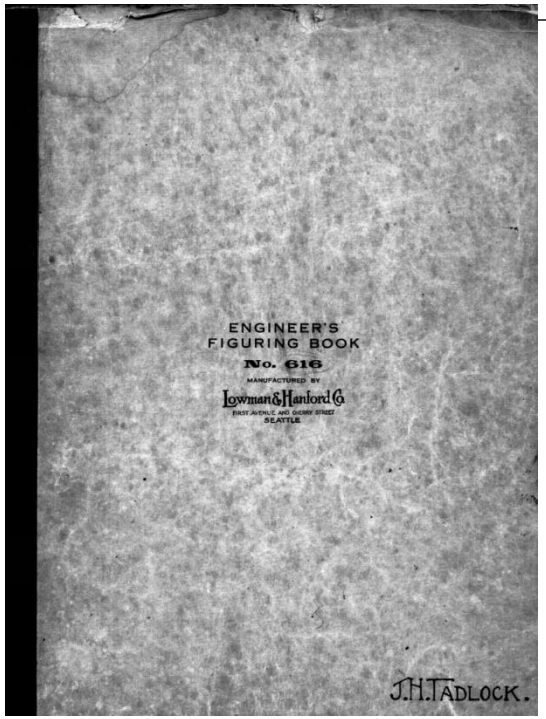
Lower Baker Dam History

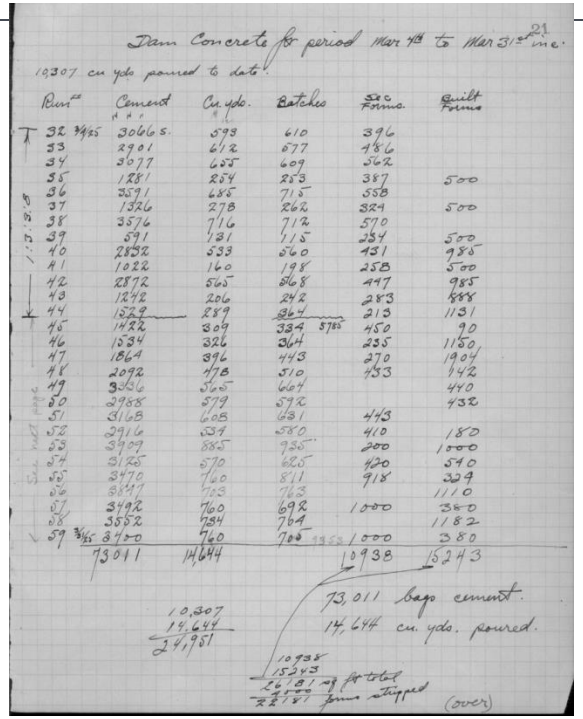


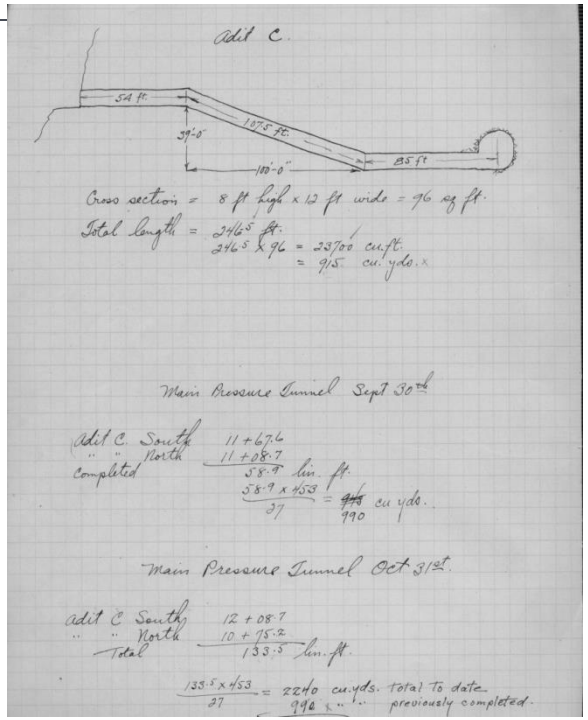
Intake shaft excavation

PUGET SOUND ENERGY

Lower Baker Dam History





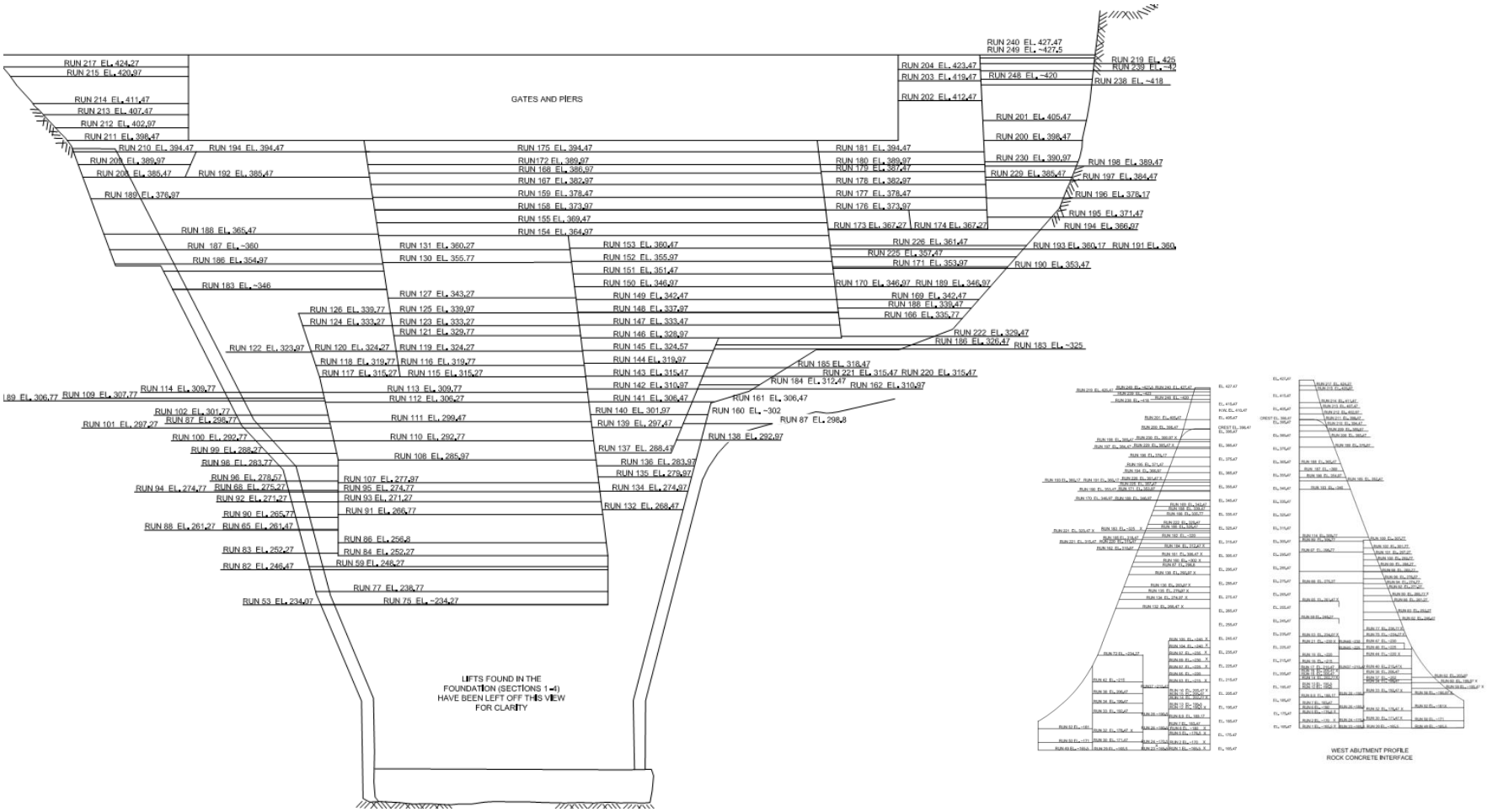


"*Engineers Figuring Book*" from construction;

- Provides a dated record of all the concrete pours
- Correlated dated on photographs to concrete pour dates
- Determined construction sequencing of the dam

PUGET SOUND ENERGY

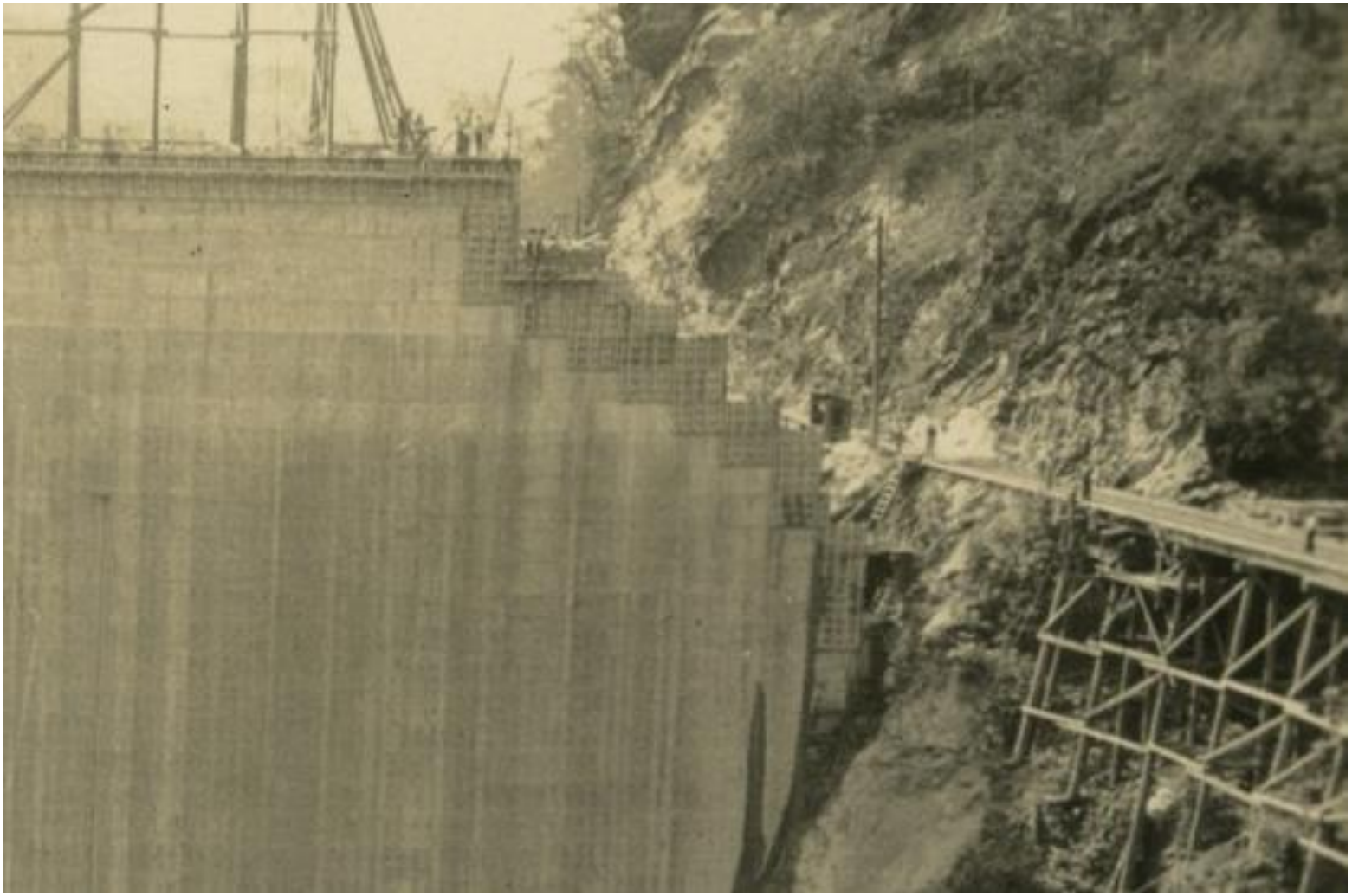
Lower Baker Dam History



CAD Model of Construction Photos

- Links construction photos to concrete placement

Lower Baker Dam History



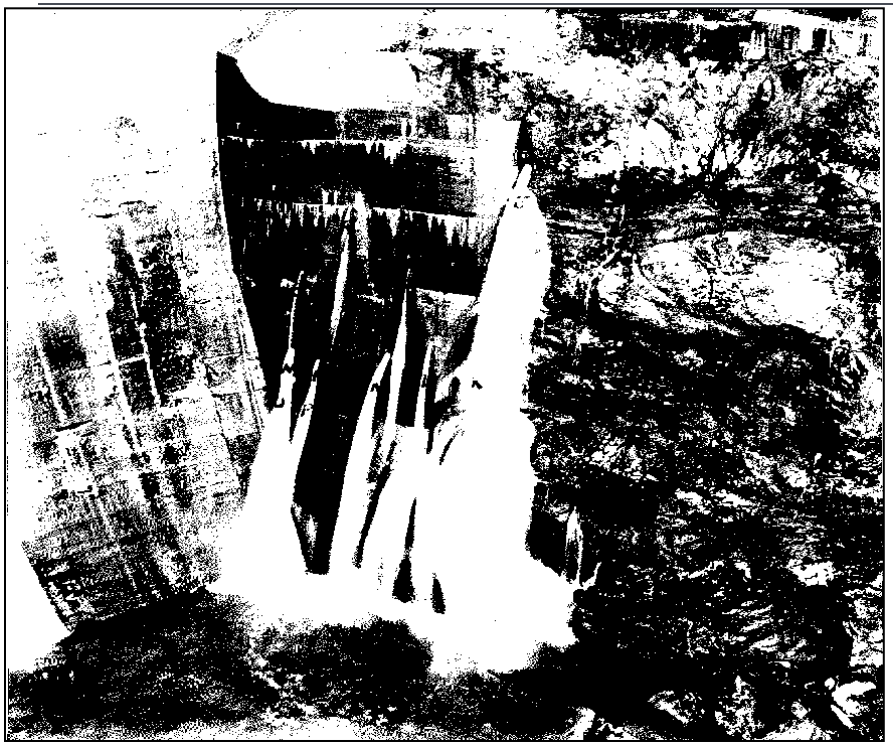
PUGET SOUND ENERGY

Lower Baker Dam Leakage Measurement

- Documentation on how leakage was measured in the past is not good.
- Past grouting efforts seemed to be triggered when the leakage rate was determined to be 100 – 150 cfs
- How much does the dam leak today?

PUGET SOUND ENERGY

Leakage Measurement



Left Abutment
1933 – 110cfs

Left Abutment
1961 – 55cfs

PUGET SOUND ENERGY

Leakage Measurement

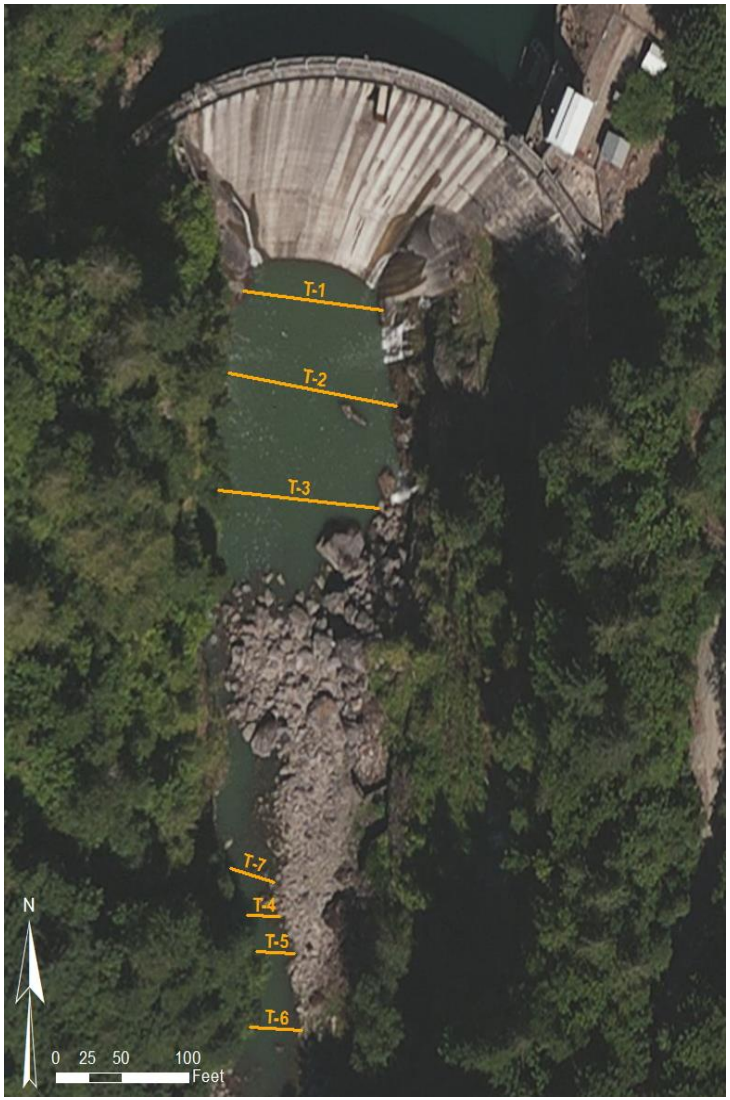
Right Abutment
1982 – 140cfs

Right Abutment
2012 - 132 cfs

PUGET SOUND ENERGY

Leakage Measurement

- **2007-2012 Acoustic Doppler Current Profiling**
- Technology uses acoustic beams along a transect to estimate velocities within the water column
- Accuracy Issues – results varied widely in a given year but seem to indicate an increase



PUGET SOUND ENERGY

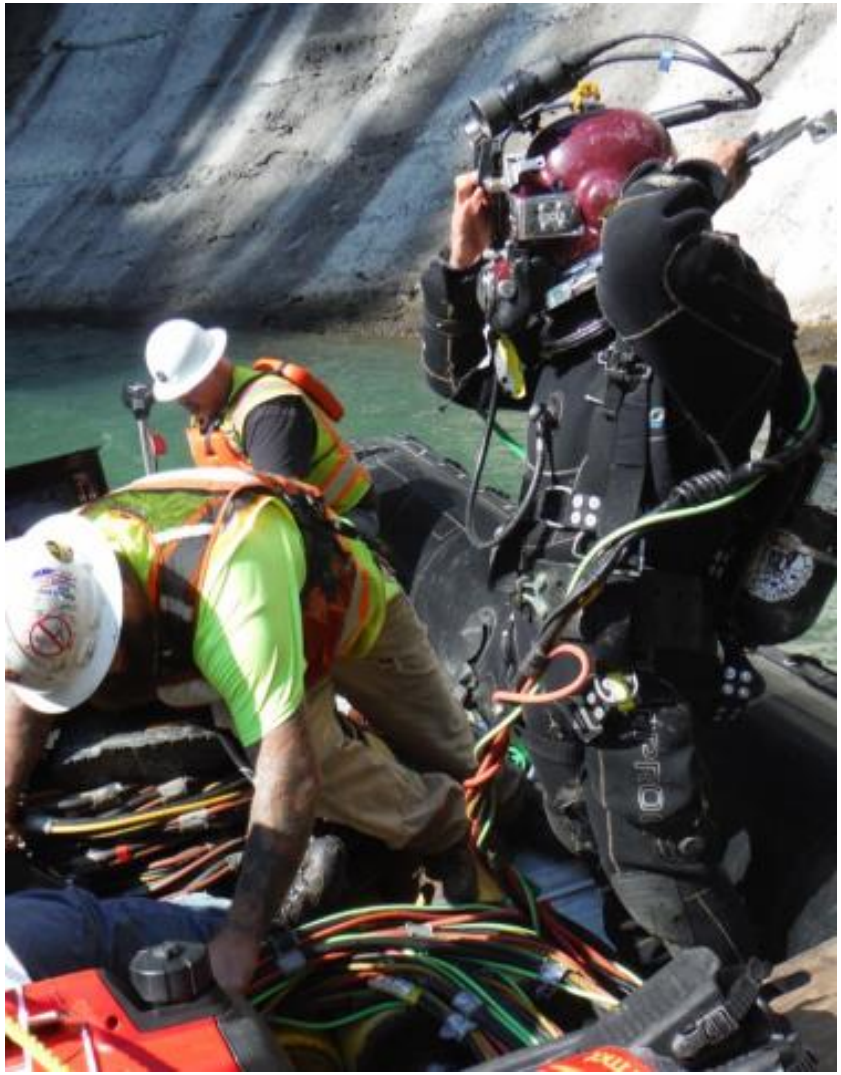
Leakage Measurement

Flow (cfs)	T-3	T-6
2012	98	132
2010	78	95
2007	78	NA

PUGET SOUND ENERGY

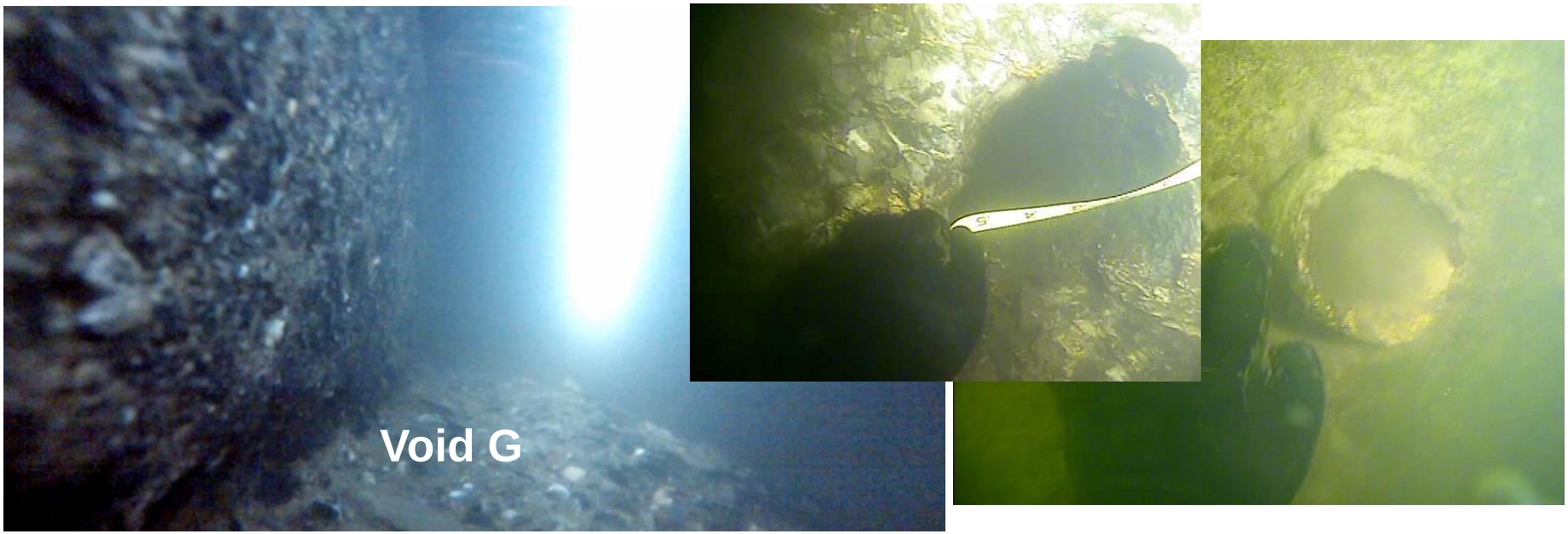
Leakage Measurement – Toe Dive Inspections

- Toe Dive inspection of the dam apron every 2 years
- Asses condition of dam apron
- Includes monitoring of several “voids” in the apron by inspections
- Mapped voids could be from scour, formed drain outlets, erosion in concrete?



PSE PUGET SOUND ENERGY

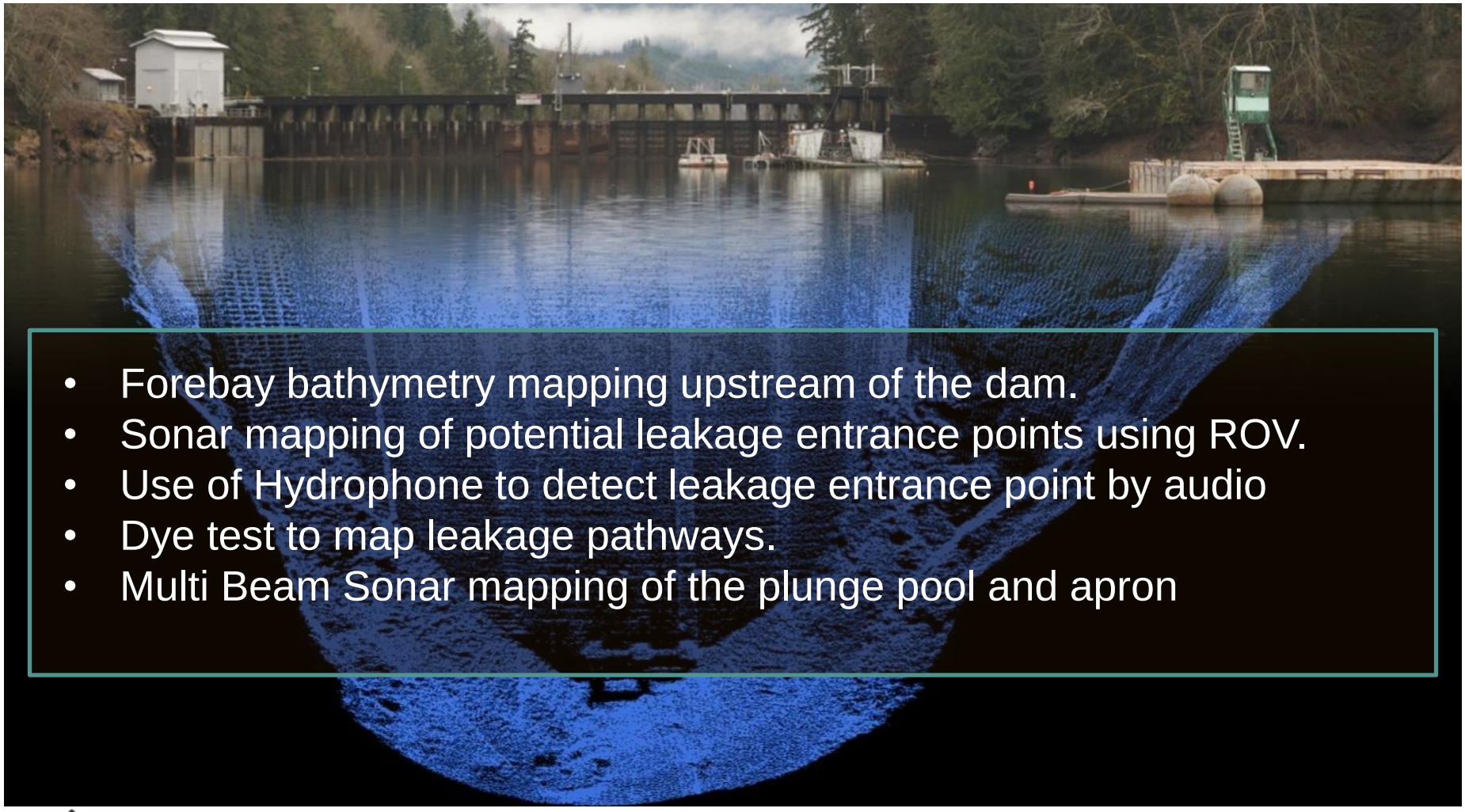
Leakage Measurement – Toe Dive Inspections



- Toe dive in 2010 showed high velocity flow from Void G located near the east end of the Apron.
- Observations prompted additional leakage investigations to better understand leakage and drainage characteristics of the dam site.

PSE PUGET SOUND ENERGY

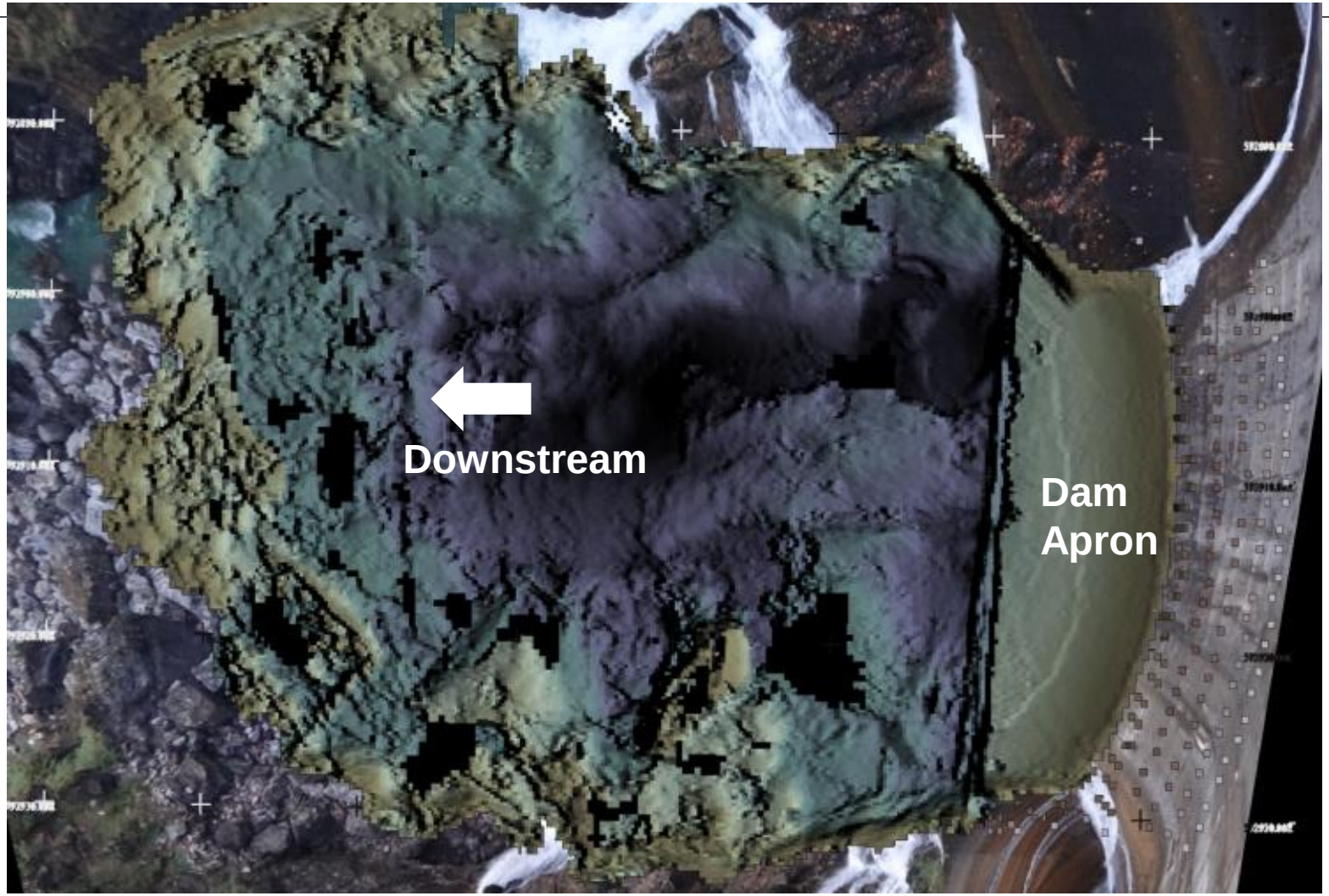
2010 Leakage Investigations



- Forebay bathymetry mapping upstream of the dam.
- Sonar mapping of potential leakage entrance points using ROV.
- Use of Hydrophone to detect leakage entrance point by audio
- Dye test to map leakage pathways.
- Multi Beam Sonar mapping of the plunge pool and apron

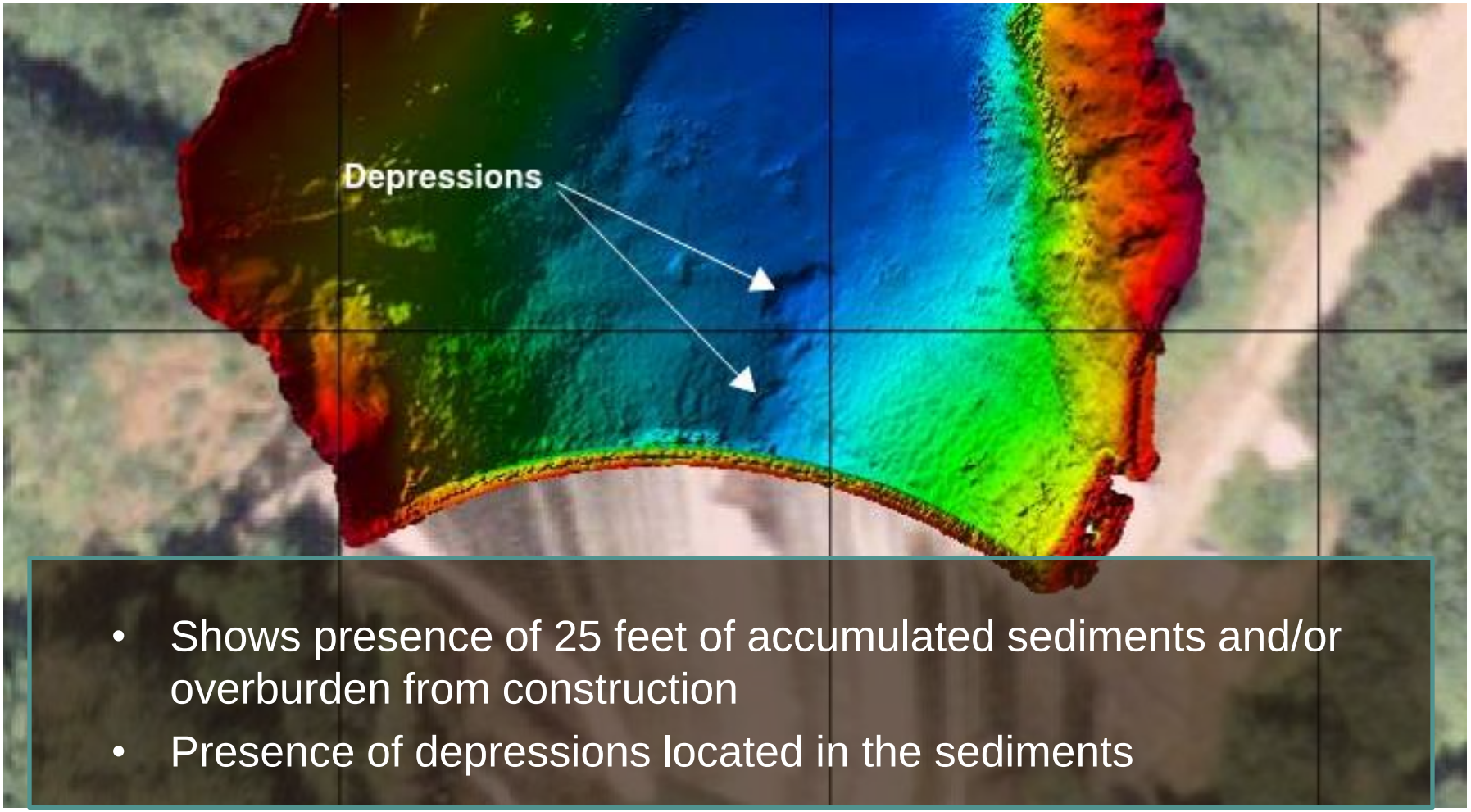
PSE PUGET SOUND ENERGY

2010 Leakage Investigations – Plunge Pool Bathymetry



PUGET SOUND ENERGY

2010 Leakage Investigations – Forebay Bathymetry



- Shows presence of 25 feet of accumulated sediments and/or overburden from construction
- Presence of depressions located in the sediments

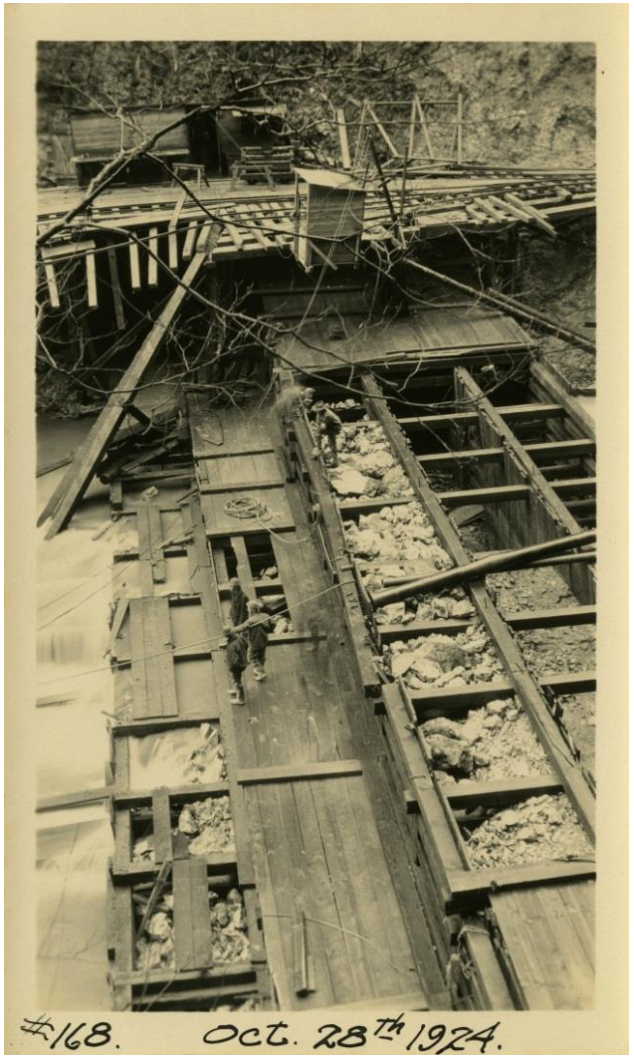
PSE PUGET SOUND ENERGY

2010 Leakage Investigations – Forebay Bathymetry

Forebay Sediments

Overburden from intake tunnel excavation

Old diversion cofferdam remnants



PUGET SOUND ENERGY

2012 Leakage Investigations

PSE PUGET SOUND ENERGY

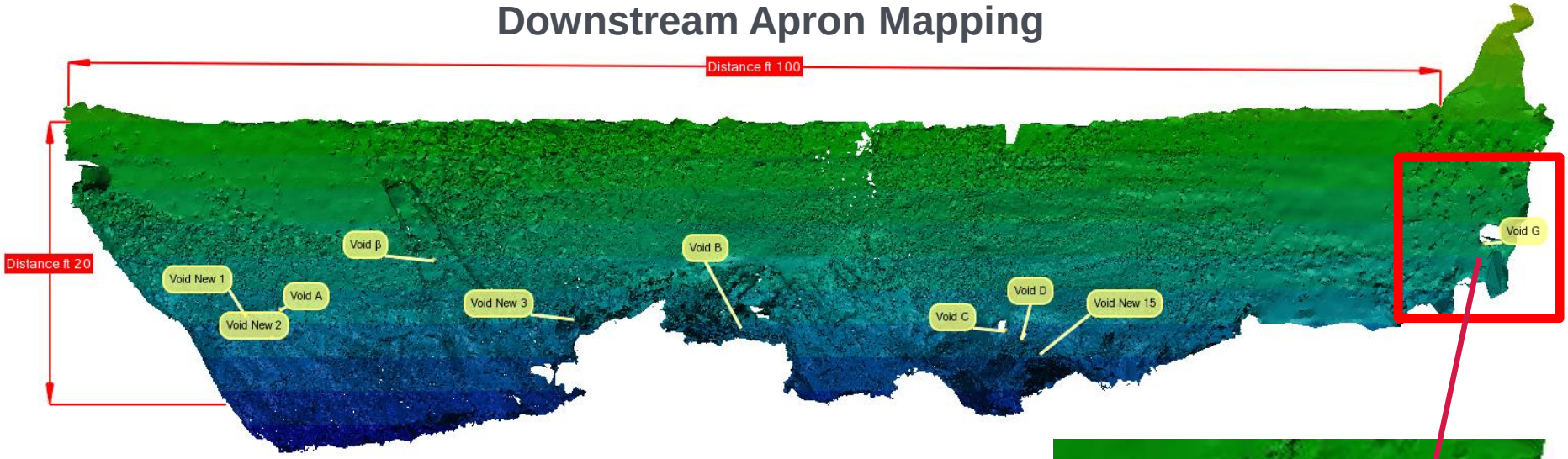
2012 Leakage Investigations

- High-Resolution Apron Mapping
- Diver Apron Inspection
- Water Sampling & Testing
- Above-Water Mapping
- Flow Measurements
- Dye Study
- Geophysical Survey
- Video Survey

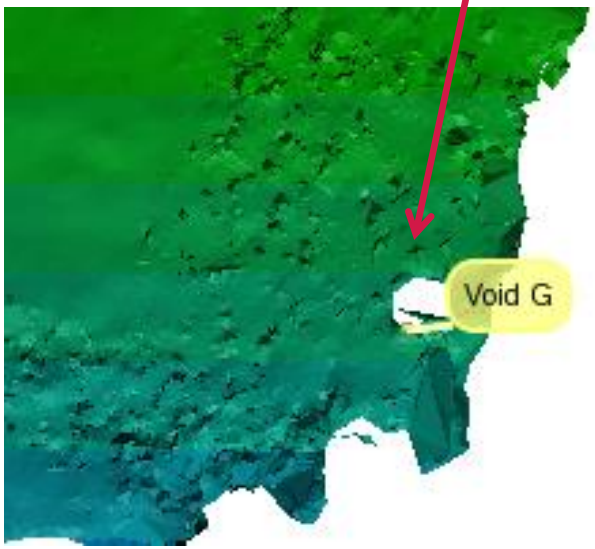
PUGET SOUND ENERGY

2012 Leakage Investigations

Downstream Apron Mapping



- Blu-Vu Scan of D.S. apron
- Able to map known voids
- Monitor changes in future scans

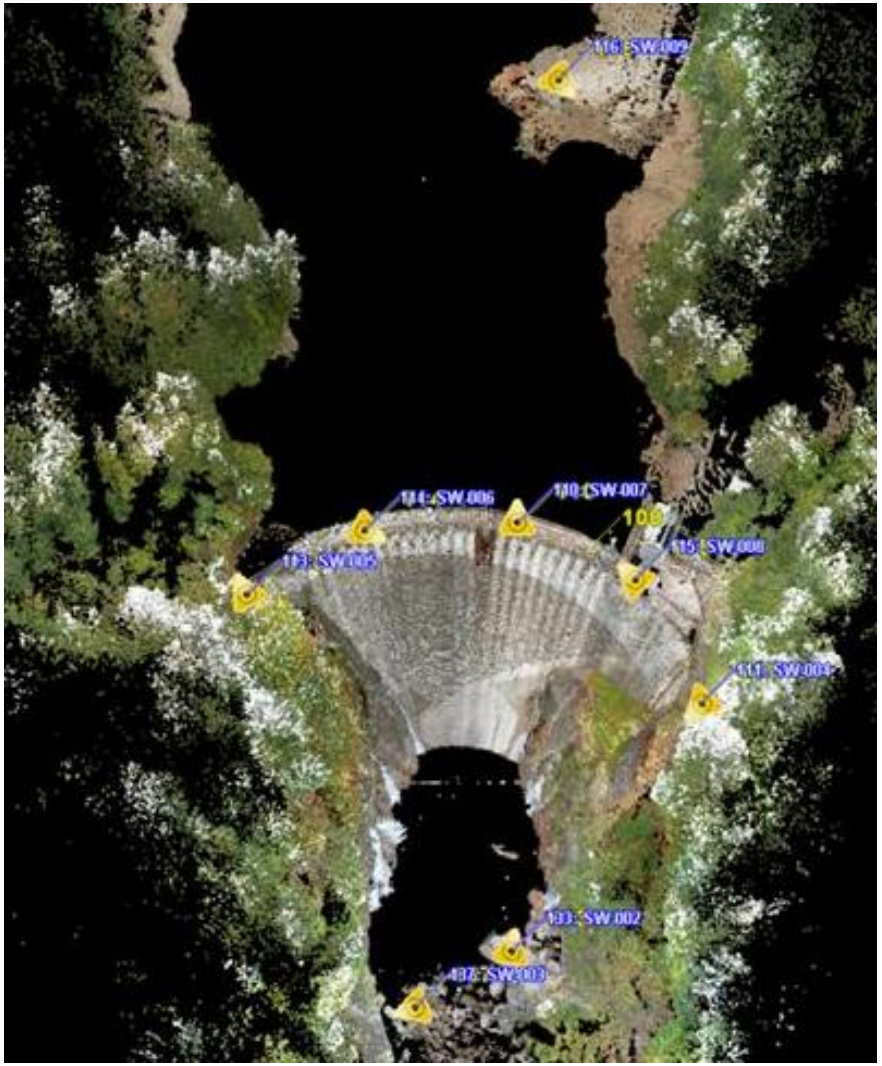


PUGET SOUND ENERGY

2012 Leakage Investigations

High Resolution Terrestrial Survey

- 3D laser scan of above water features
- Forebay
- Dam
- D.S. face
- Abutments & plunge pool

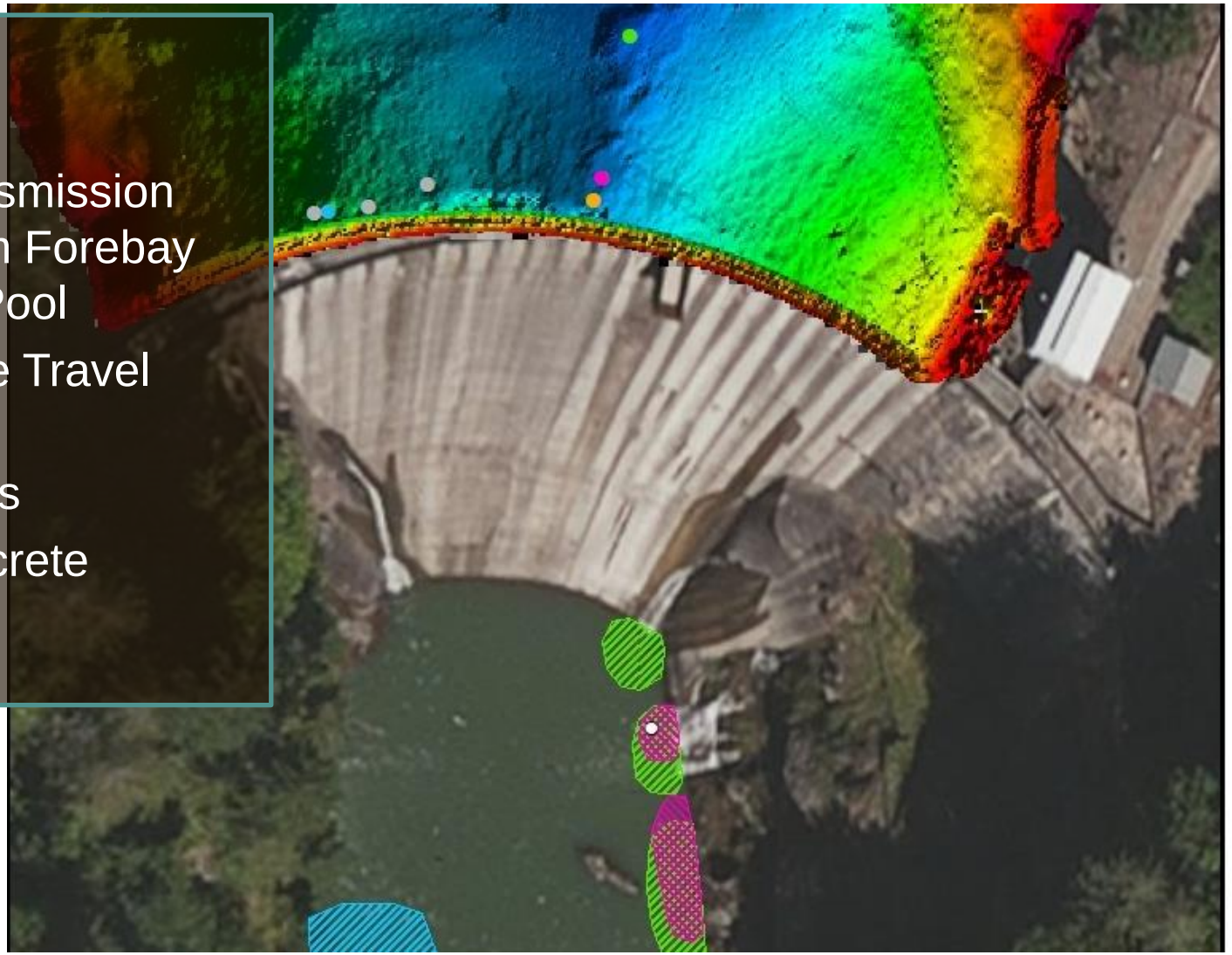


PUGET SOUND ENERGY

2012 Leakage Investigations

Dye Study

- Rapid Transmission Times From Forebay to Plunge Pool
- 3-10 Minute Travel Time
- 0.4 – 1.4 fps
- Shows Discrete Pathways

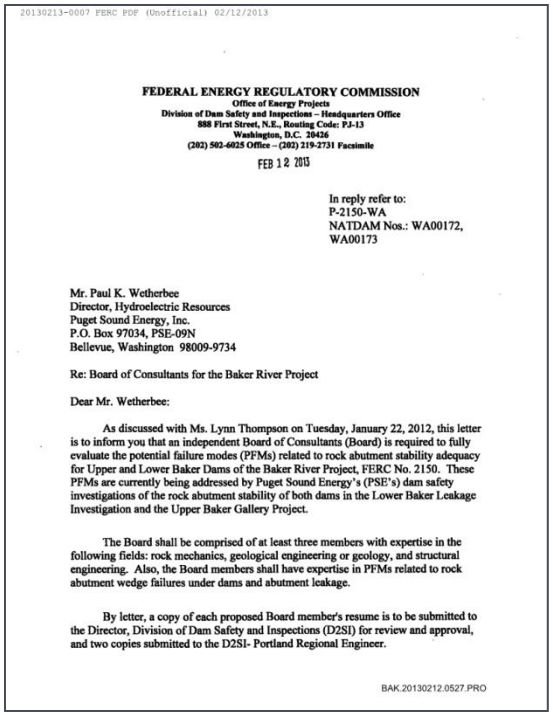


PSE PUGET SOUND ENERGY

2013 Board of Consultants Formed

BOC Scoped to Assess

- Previous abutment and leakage investigations
- Proposed abutment explorations
- Credible rock abutment wedges that could cause dam failure
- Surveillance and monitoring required
- Dam safety related to grouting



20130213-0007 FERC PDF (Unofficial) 02/12/2013

FEDERAL ENERGY REGULATORY COMMISSION
Office of Energy Projects
Division of Dam Safety and Inspections – Headquarters Office
888 First Street, N.E., Routing Code: PJ-13
Washington, D.C. 20426
(202) 502-6025 Office – (202) 219-2731 Facsimile

FEB 12 2013

In reply refer to:
P-2150-WA
NATDAM Nos.: WA00172, WA00173

Mr. Paul K. Wetherbee
Director, Hydroelectric Resources
Puget Sound Energy, Inc.
P.O. Box 97034, PSE-09N
Bellevue, Washington 98009-9734

Re: Board of Consultants for the Baker River Project

Dear Mr. Wetherbee:

As discussed with Ms. Lynn Thompson on Tuesday, January 22, 2012, this letter is to inform you that an independent Board of Consultants (Board) is required to fully evaluate the potential failure modes (PFMs) related to rock abutment stability adequacy for Upper and Lower Baker Dams of the Baker River Project, FERC No. 2150. These PFMs are currently being addressed by Puget Sound Energy's (PSE's) dam safety investigations of the rock abutment stability of both dams in the Lower Baker Leakage Investigation and the Upper Baker Gallery Project.

The Board shall be comprised of at least three members with expertise in the following fields: rock mechanics, geological engineering or geology, and structural engineering. Also, the Board members shall have expertise in PFMs related to rock abutment wedge failures under dams and abutment leakage.

By letter, a copy of each proposed Board member's resume is to be submitted to the Director, Division of Dam Safety and Inspections (D2SI) for review and approval, and two copies submitted to the D2SI- Portland Regional Engineer.

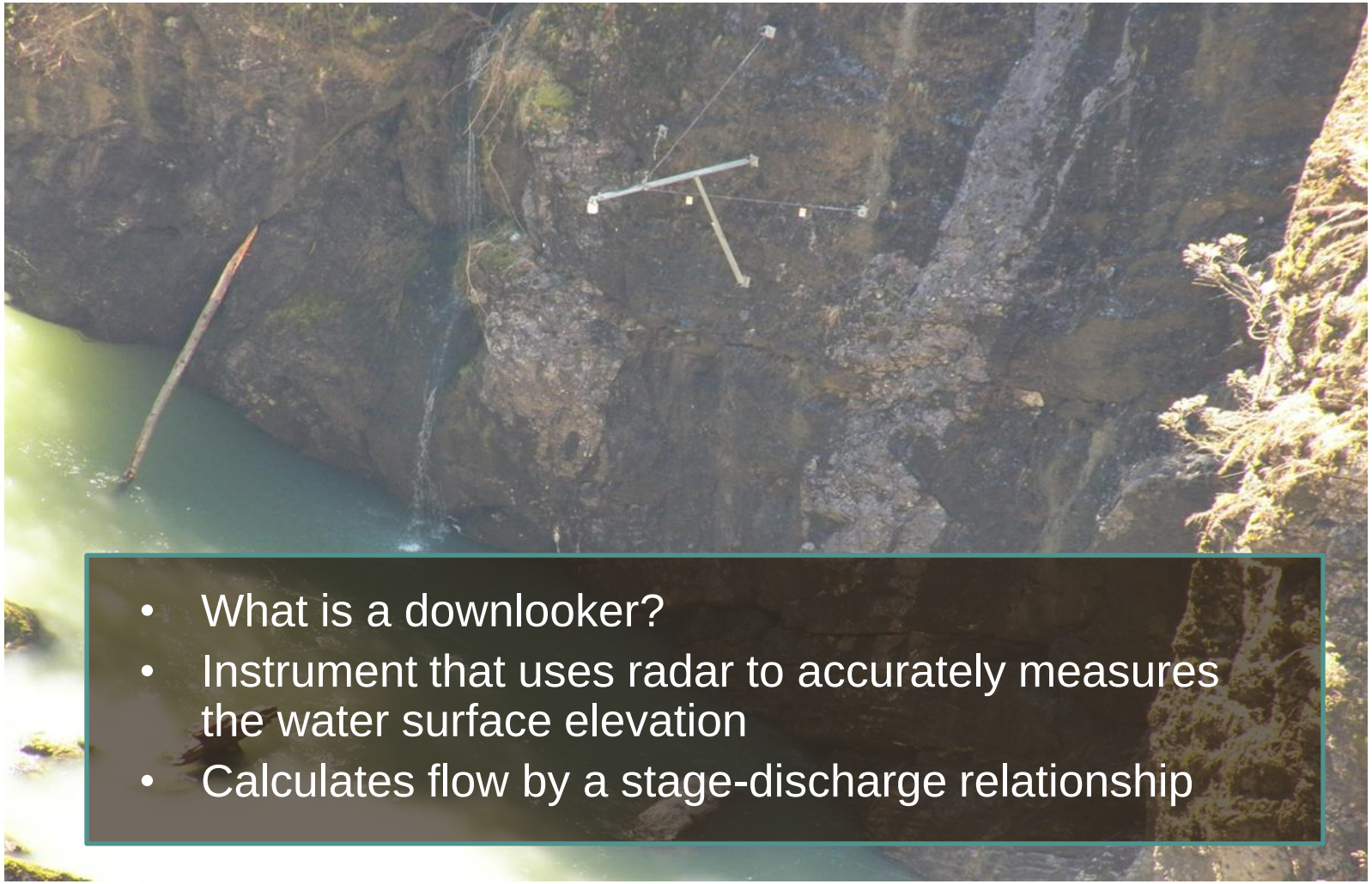
BAK.20130212.0527.PRO

BOC meeting No. 1 Recommendations

- Accurately measure leakage from the dam
- Improve on leakage investigations methods
- Use all available recent and historic information to create a geologic model of the dam to define leakage pathways and review abutment stability.

PUGET SOUND ENERGY

Downlooker Instrumentation



- What is a downlooker?
- Instrument that uses radar to accurately measures the water surface elevation
- Calculates flow by a stage-discharge relationship

PUGET SOUND ENERGY

Downlooker Instrumentation

- Installed in November 2012 to support the early detection warning system and monitor leakage.
- Re-purposed in 2014 to primarily monitor leakage
- Measures leakage rate to within 3 or 4% of actual flow
- Rate is dependent upon pool elevation with max rate of 138cfs

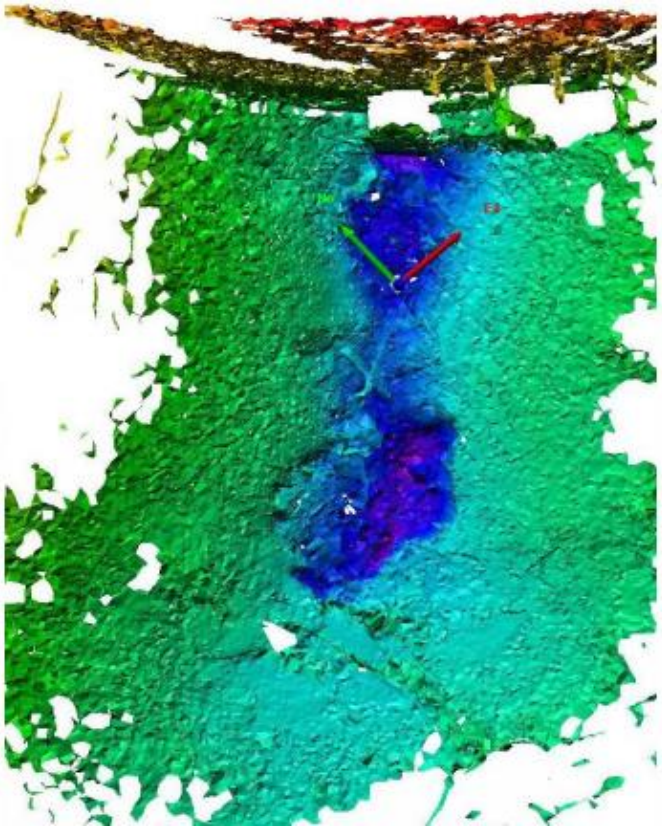
PSE PUGET SOUND ENERGY

2014 Leakage Investigations

- Toe Dive
- High Resolution Multibeam Scanning Sonar
- ROV Investigation
- Dye Study & Water Sampling
- Geological Mapping in Forebay & Downstream Channel
- Terrestrial Laser Scanning

PUGET SOUND ENERGY

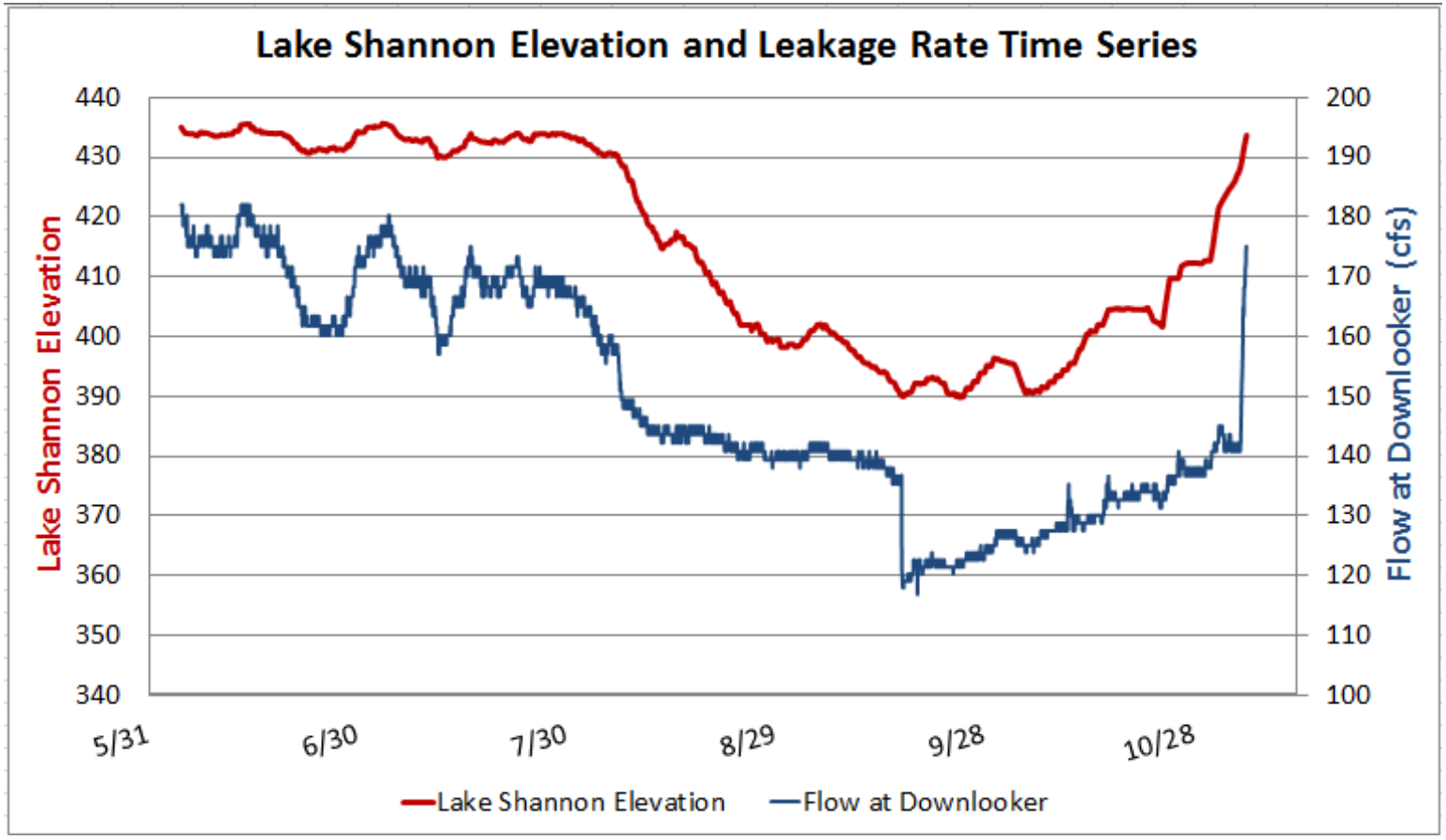
2014 Leakage Investigations



- ROV video reconnaissance of forebay depression
- High resolution Blue-Vu scanning of depression

PUGET SOUND ENERGY

2014 Leakage Investigations



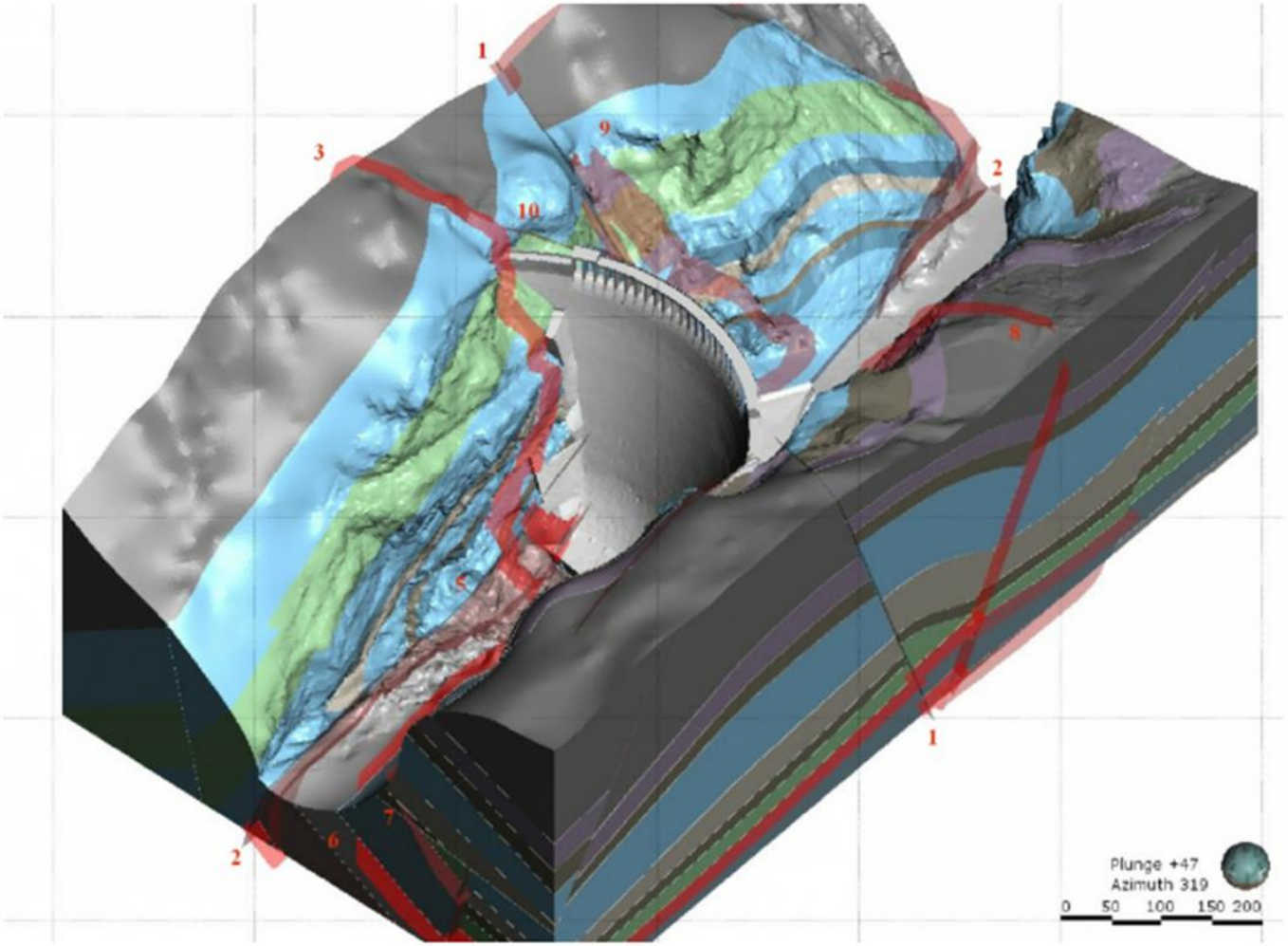
Downlooker data during 2014 Leakage Investigations

PUGET SOUND ENERGY

2014 Leakage Investigations

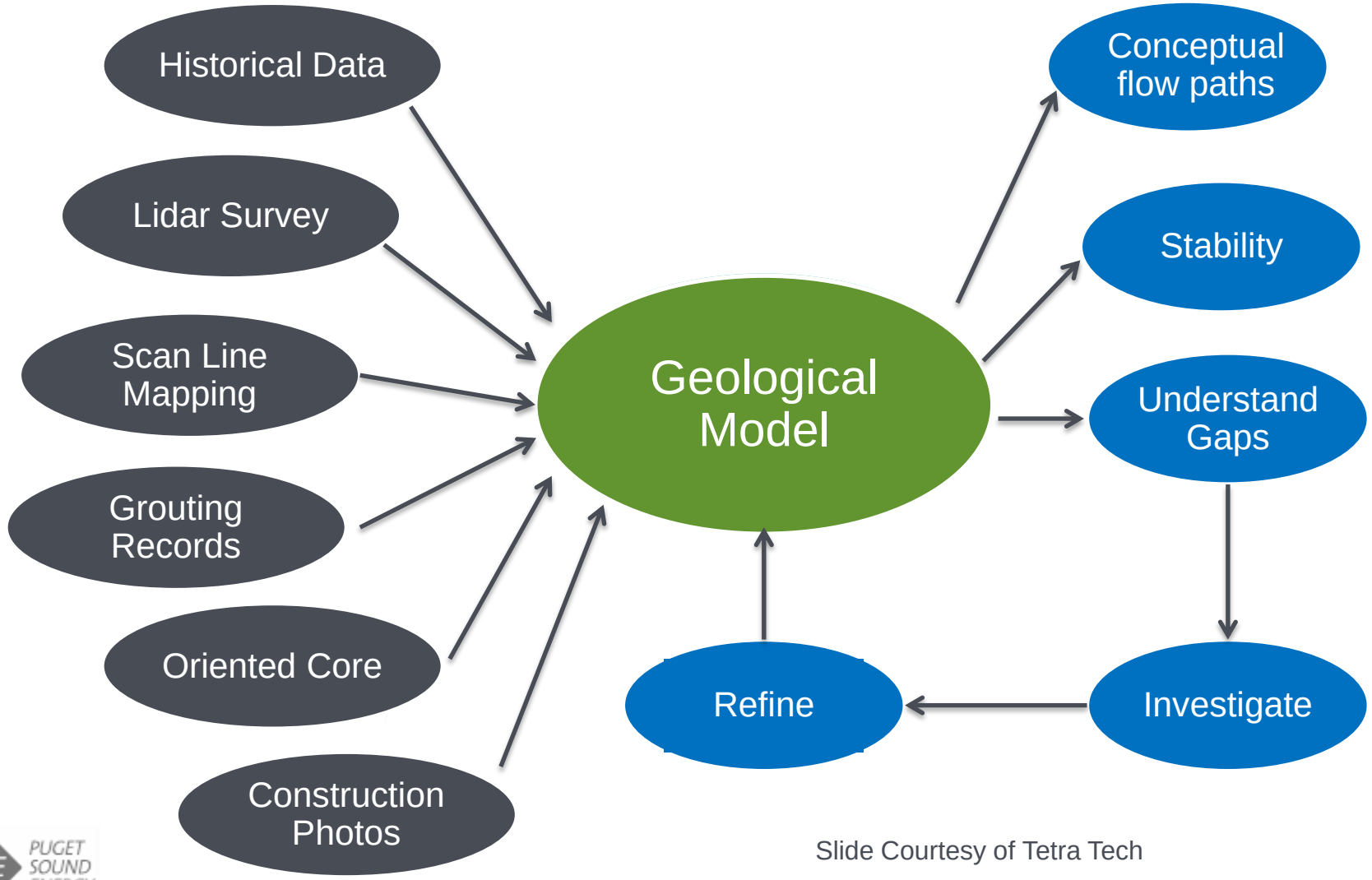
PUGET SOUND ENERGY

Geologic Model



PUGET SOUND ENERGY

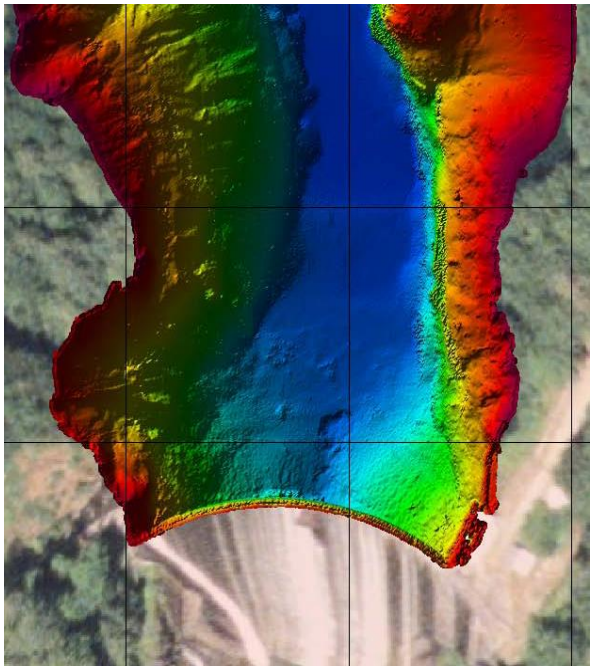
Geologic Model



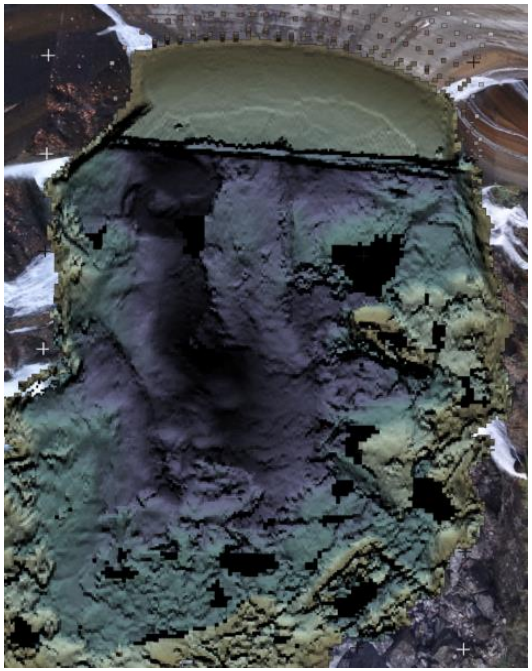
Slide Courtesy of Tetra Tech

PSE PUGET SOUND ENERGY

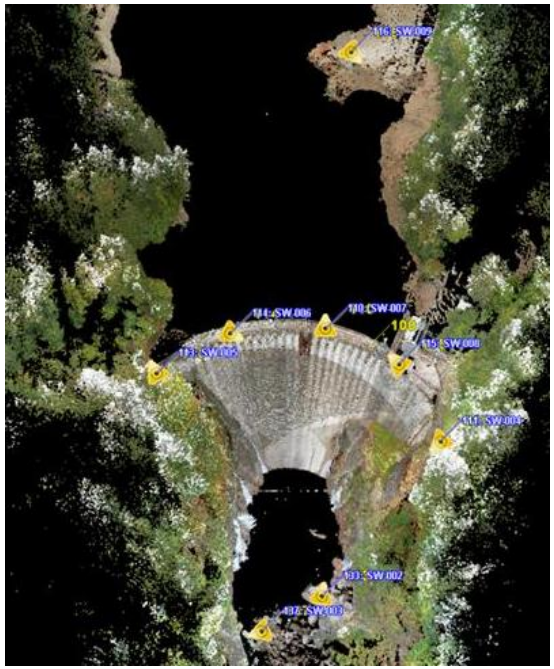
Geologic Model – 3D CAD Model



Forebay bathymetry



Plunge pool bathymetry



Terrestrial laser survey

- Combine existing mapping
- Create high resolution mapping model of entire dam site
- Becomes the foundation for the geologic model

PUGET SOUND ENERGY

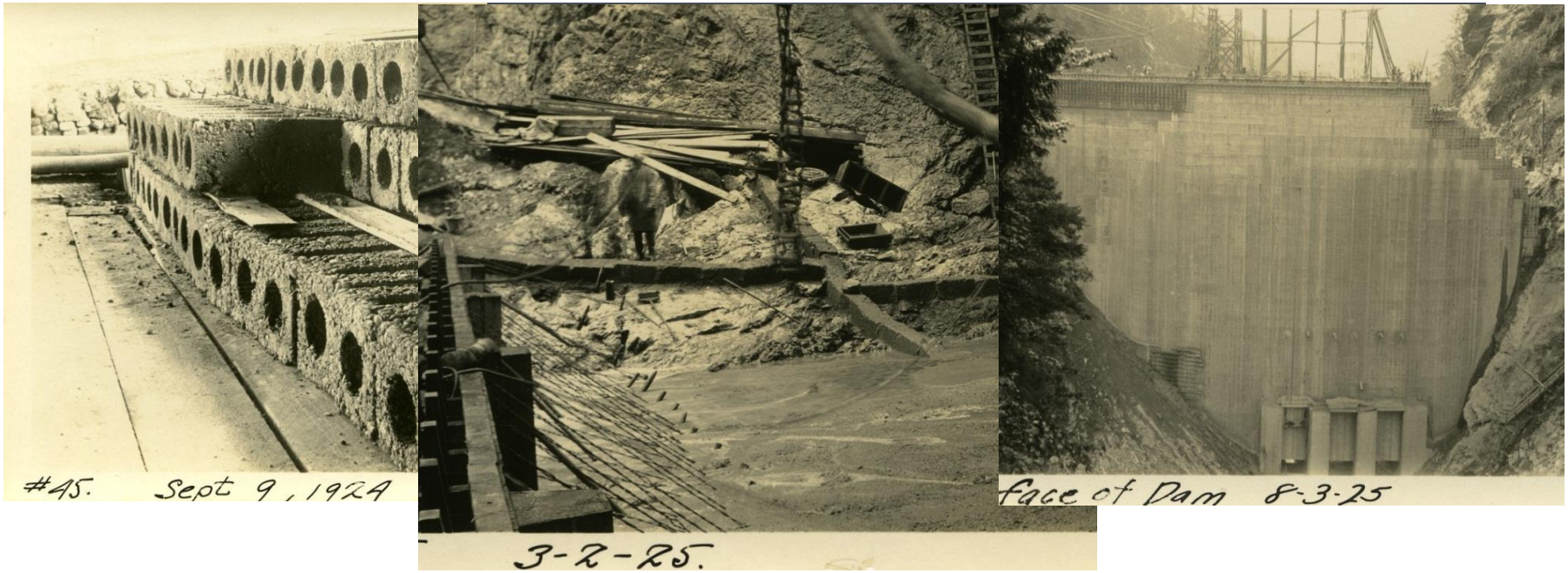
Geologic Model – 3D CAD Model

PUGET SOUND ENERGY

Geologic Model – 3D CAD Model

PUGET SOUND ENERGY

Geologic Model – Historical Data



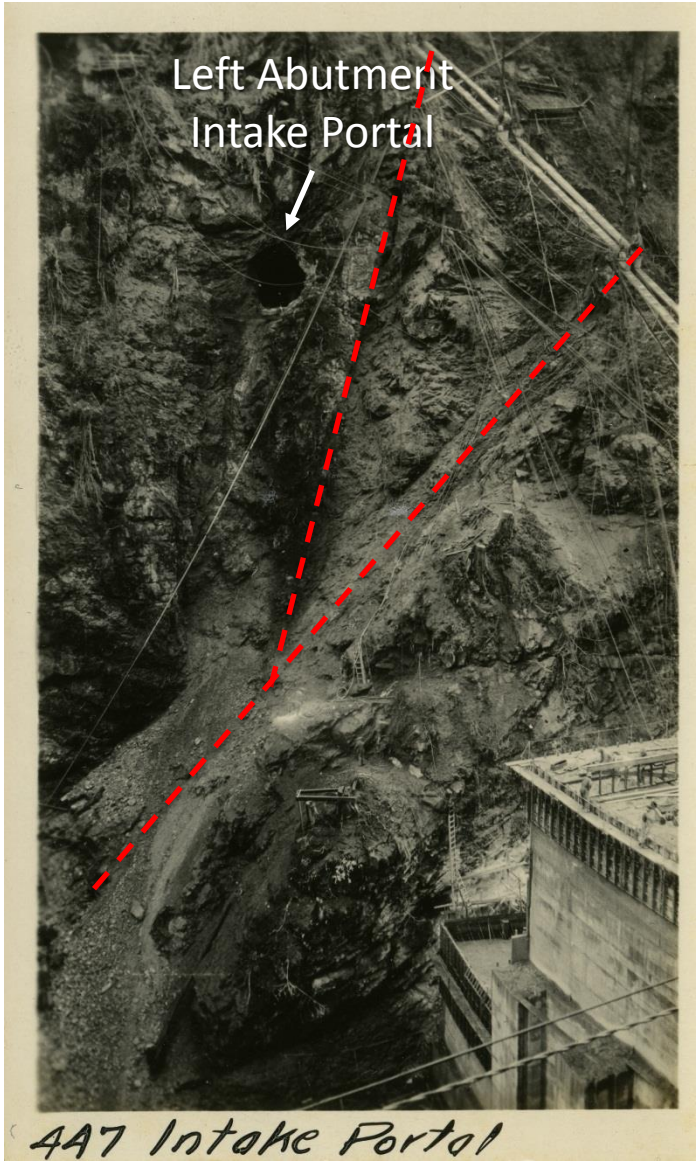
Examination of Historical Photographs

Geologic Model – Historical Data

Shale seem in limestone abutments

PUGET SOUND ENERGY

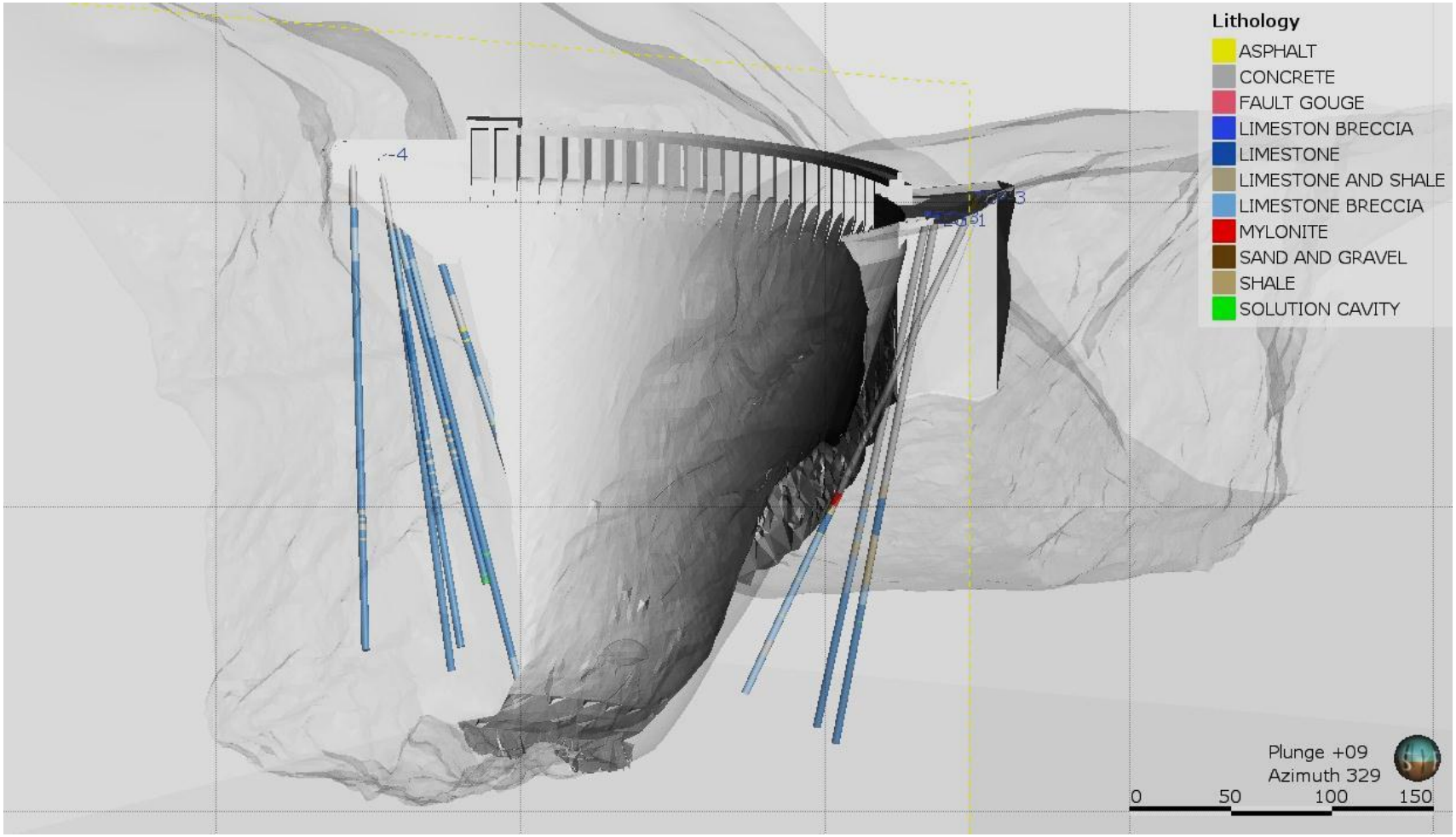
Geologic Model – Historical Data



Possible Fault Zones

PUGET SOUND ENERGY

Geologic Model – Historical Data



Re-logging of existing cores

PUGET SOUND ENERGY

Geologic Model – Historical Data

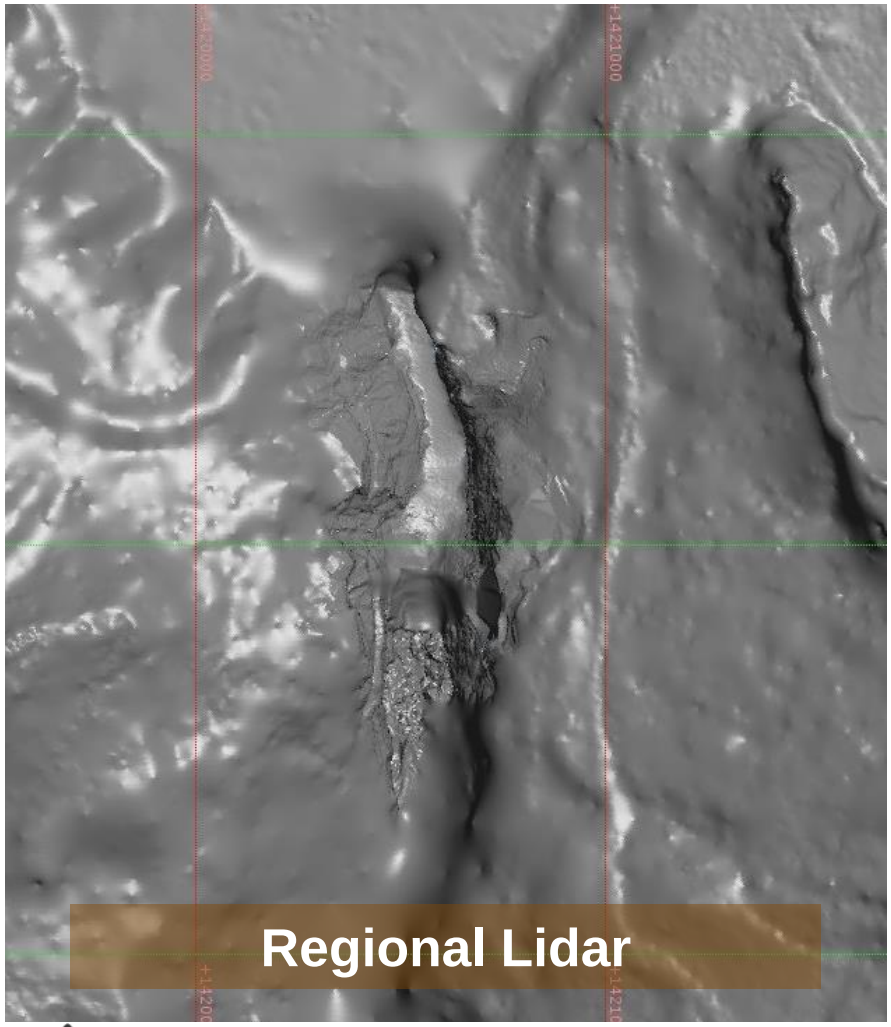
PUGET SOUND ENERGY

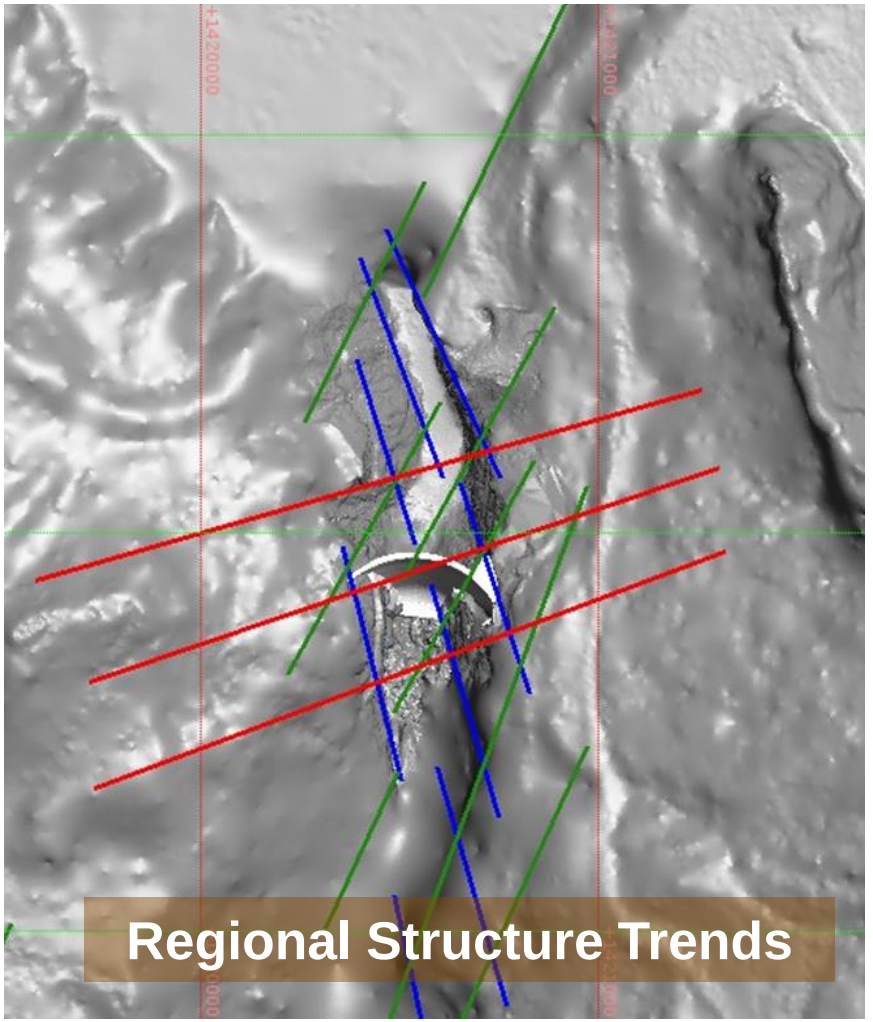
Geologic Model – Historical Data

- Previous scan lines
- Previous geologic reports & mapping

PUGET SOUND ENERGY

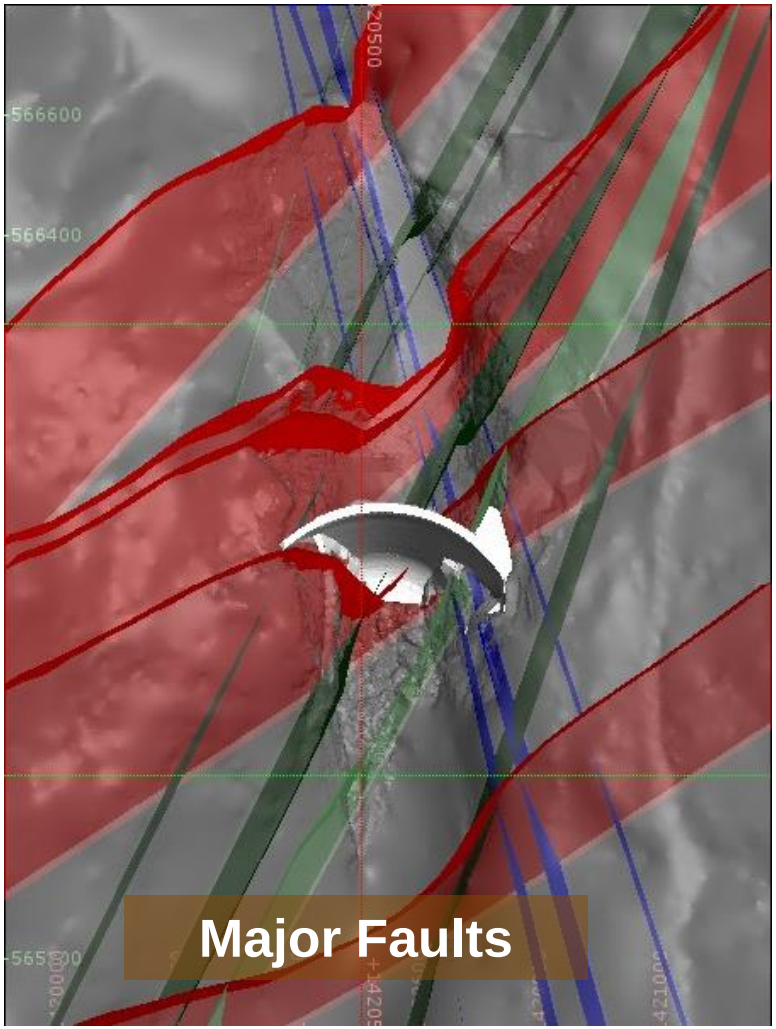
Geologic Model – Regional Lidar

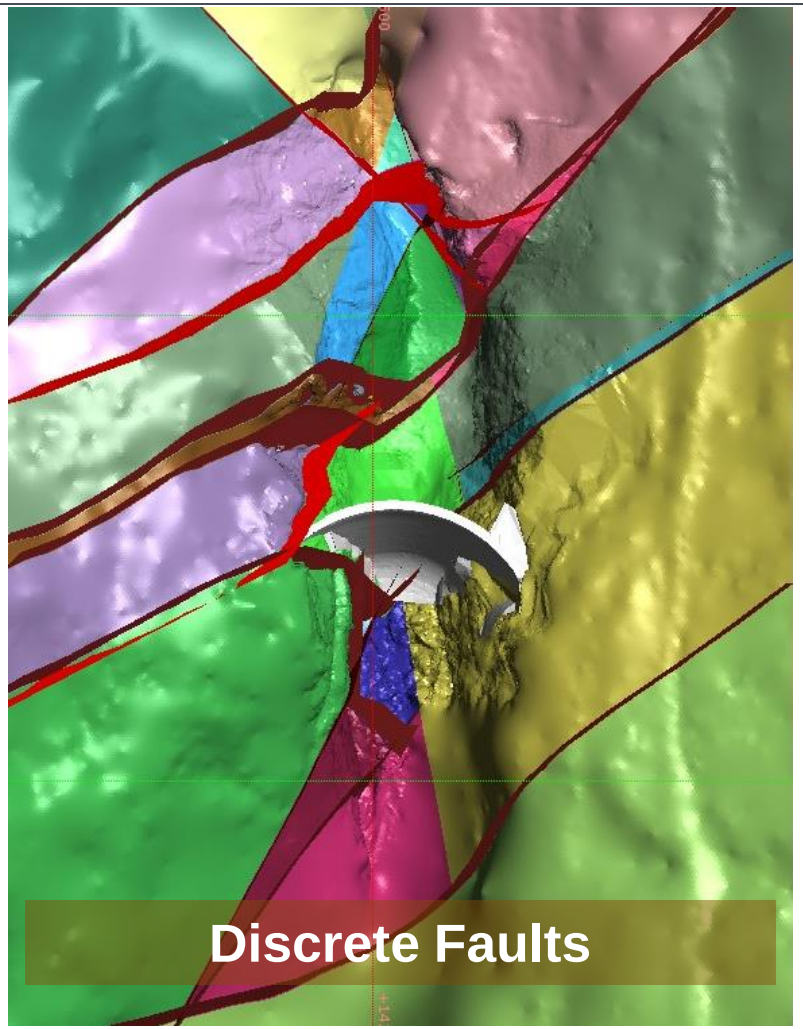




PUGET SOUND ENERGY

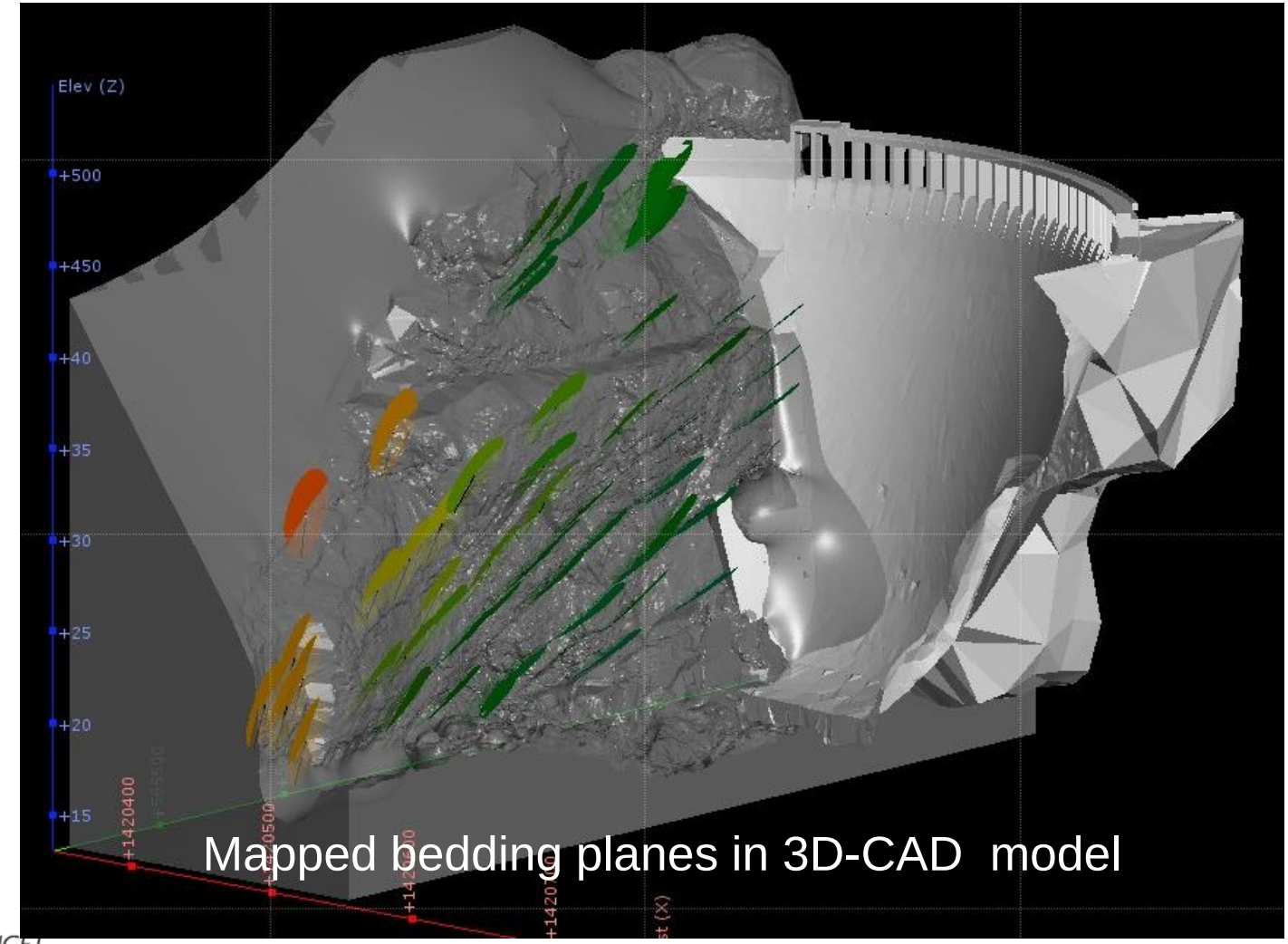
Geologic Model – Regional Lidar





PUGET SOUND ENERGY

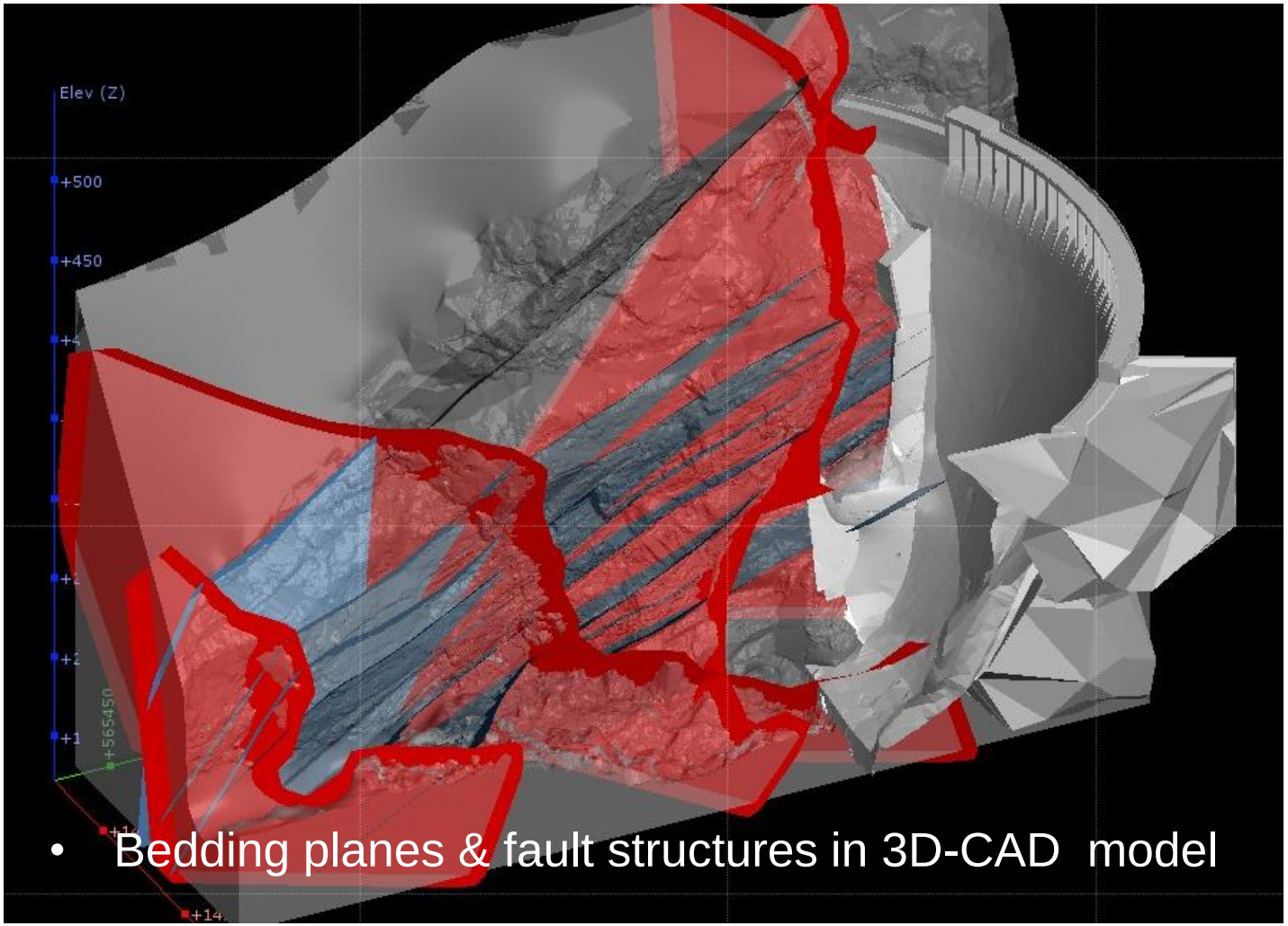
Geologic Model – West Abutment Mapping



Mapped bedding planes in 3D-CAD model

PUGET SOUND ENERGY

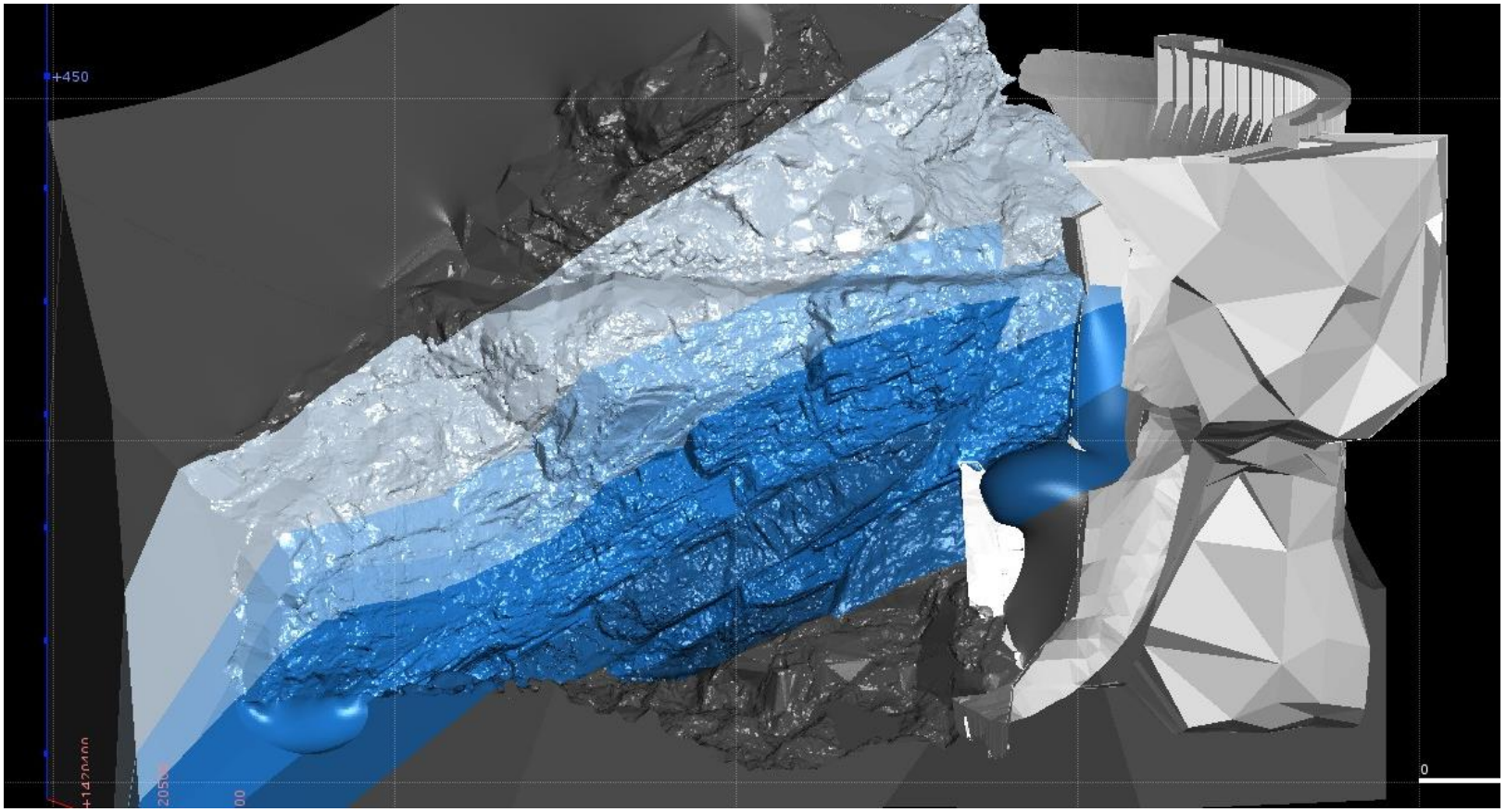
Geologic Model- 3D CAD mapping



- Bedding planes & fault structures in 3D-CAD model

PUGET SOUND ENERGY

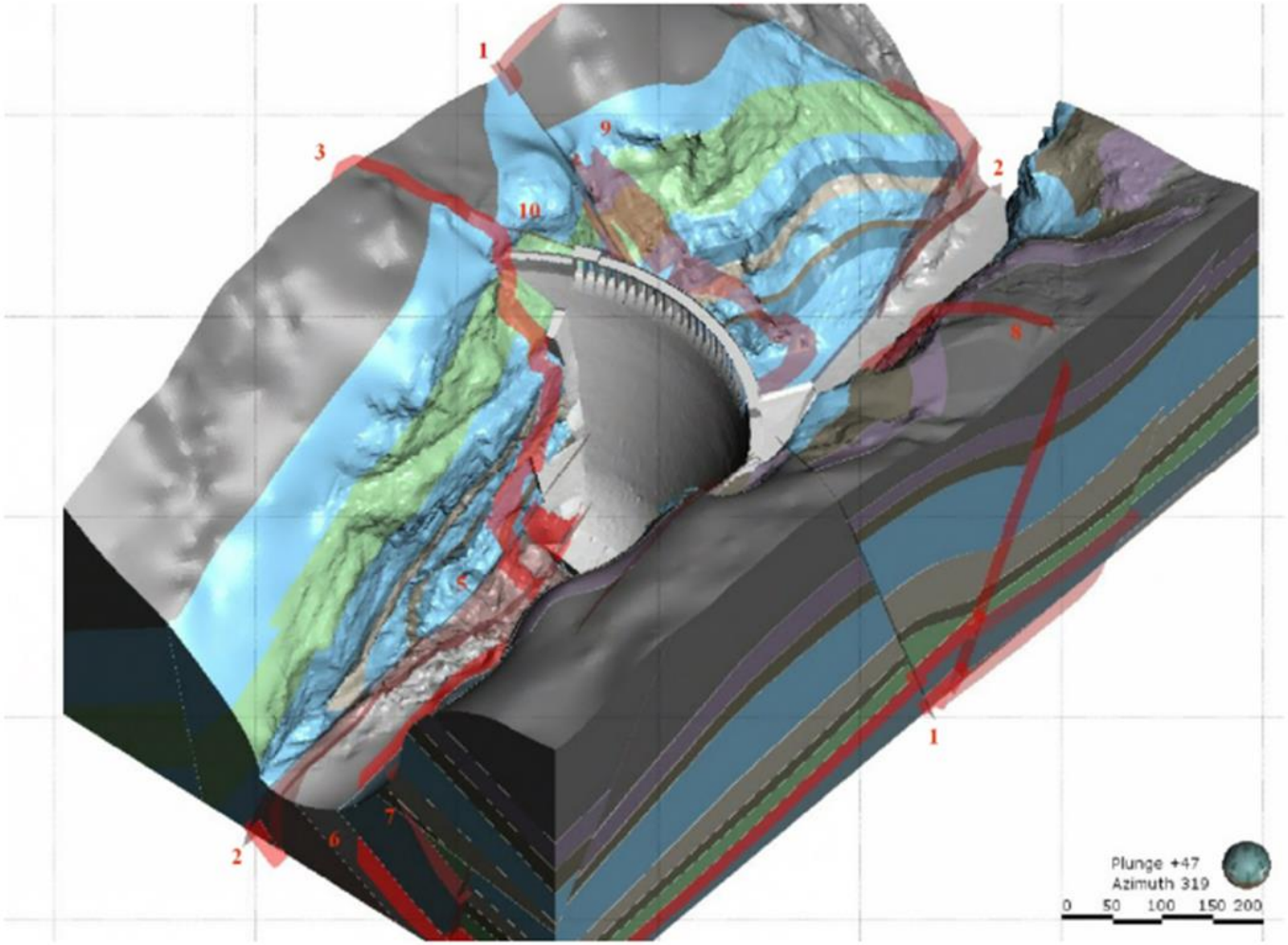
Geologic Model- 3D CAD mapping



Limestone units modelled

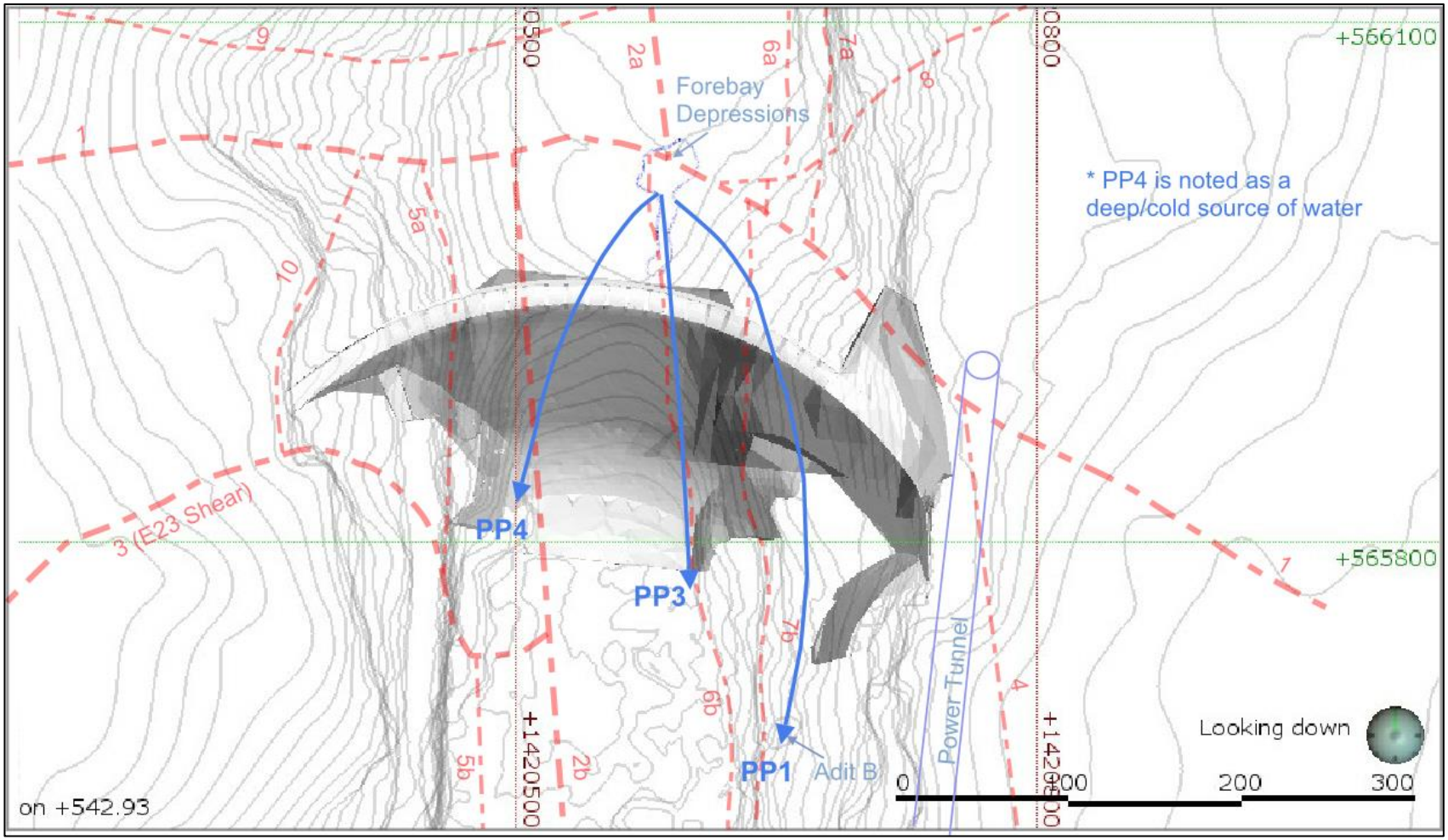
PUGET SOUND ENERGY

Geologic Model



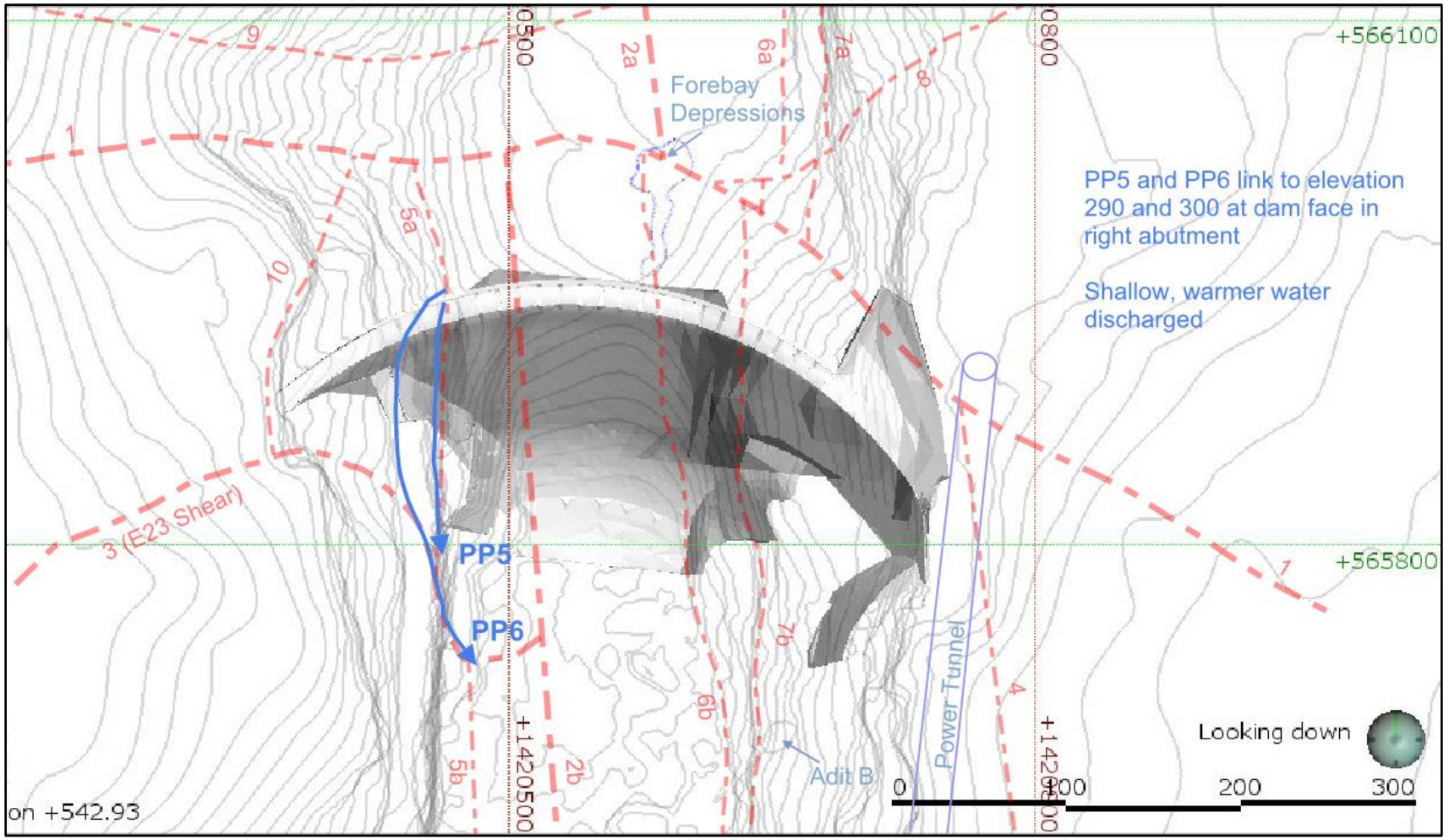
PSE PUGET SOUND ENERGY

Relate Leakage to Geology



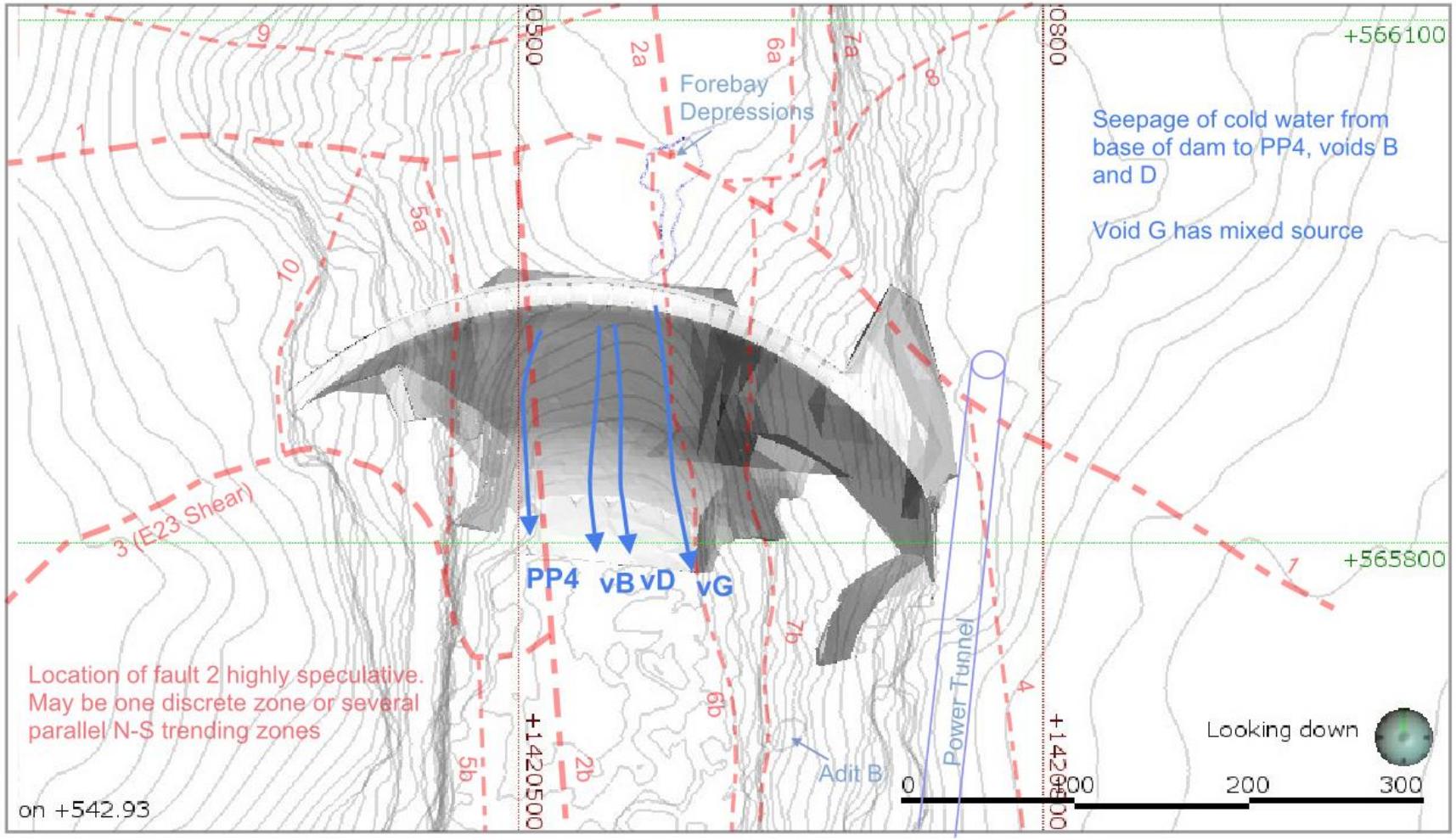
PUGET SOUND ENERGY

Relate Leakage to Geology

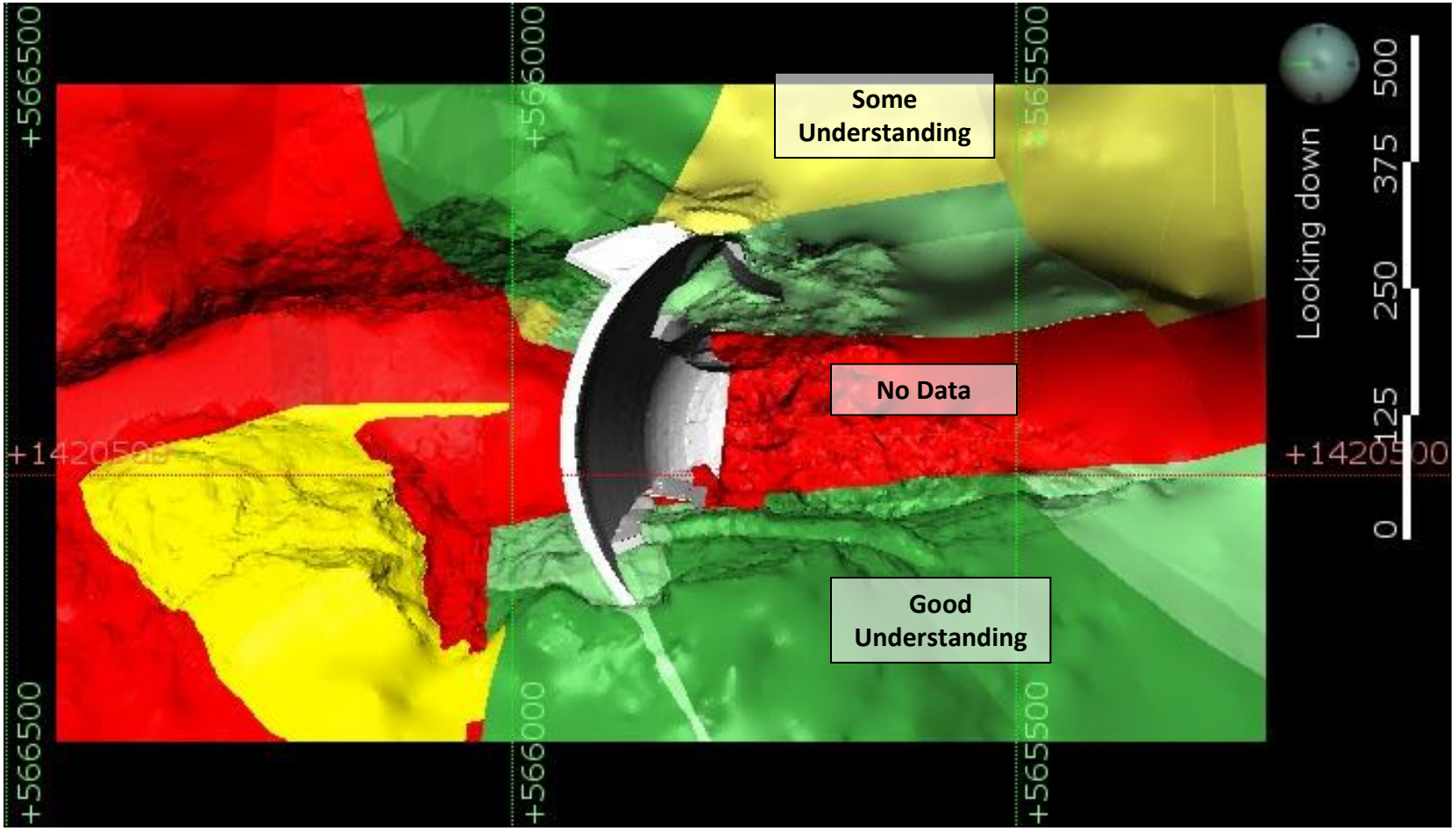


PUGET SOUND ENERGY

Relate Leakage to Geology

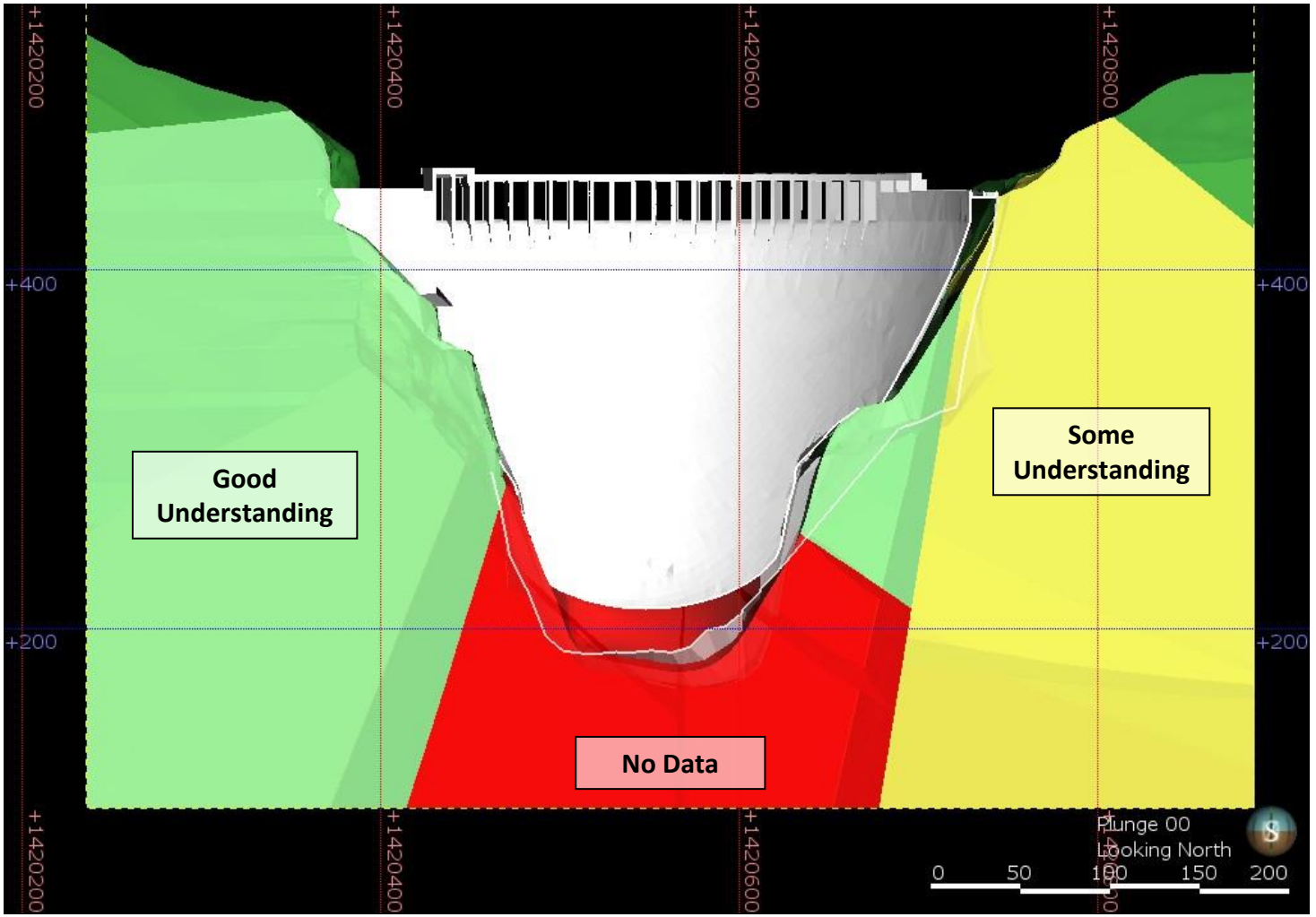


Geologic Model – Gap Assessment



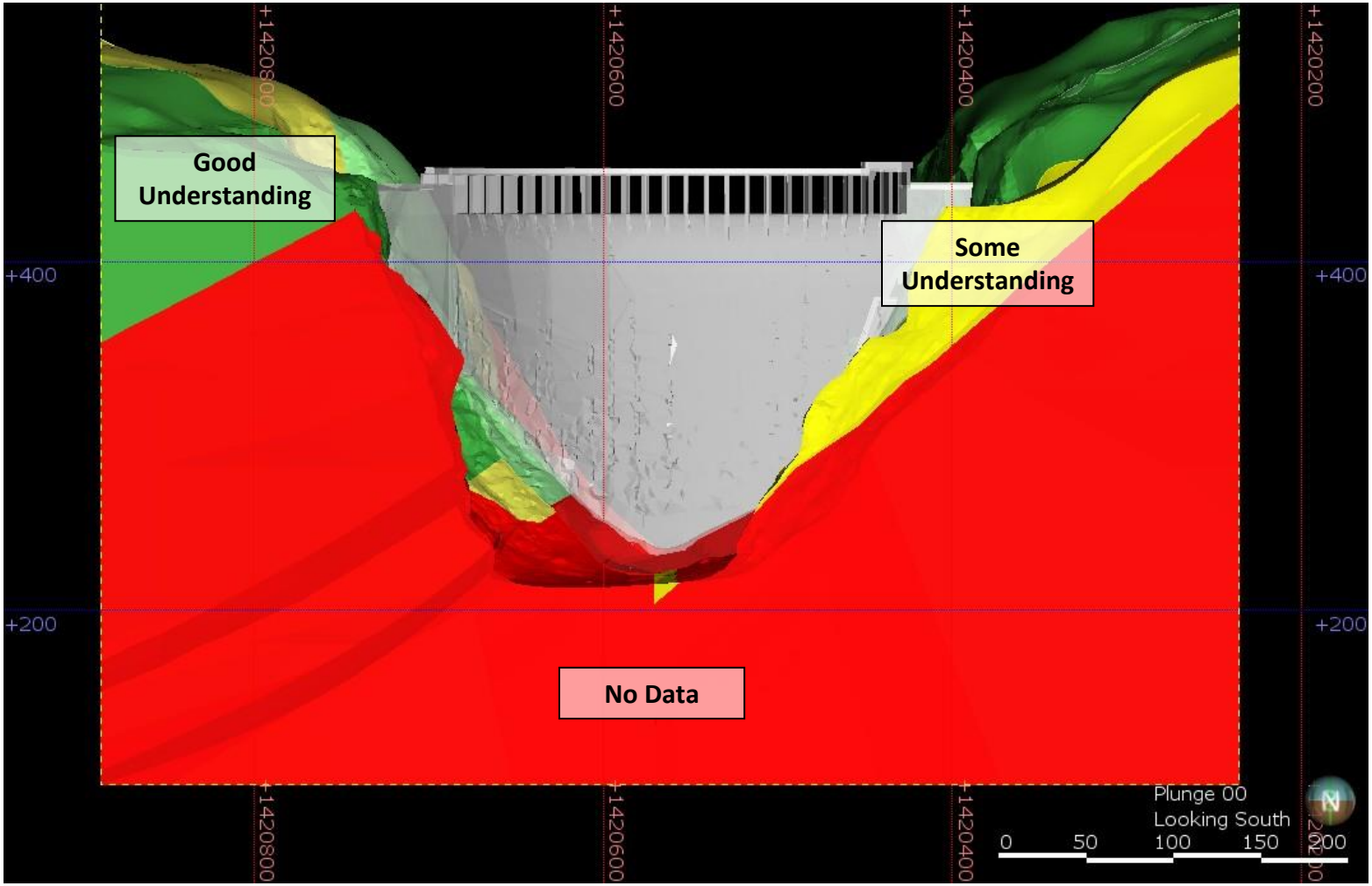
PUGET SOUND ENERGY

Geologic Model – Gap Assessment



Downstream View

Geologic Model – Gap Assessment



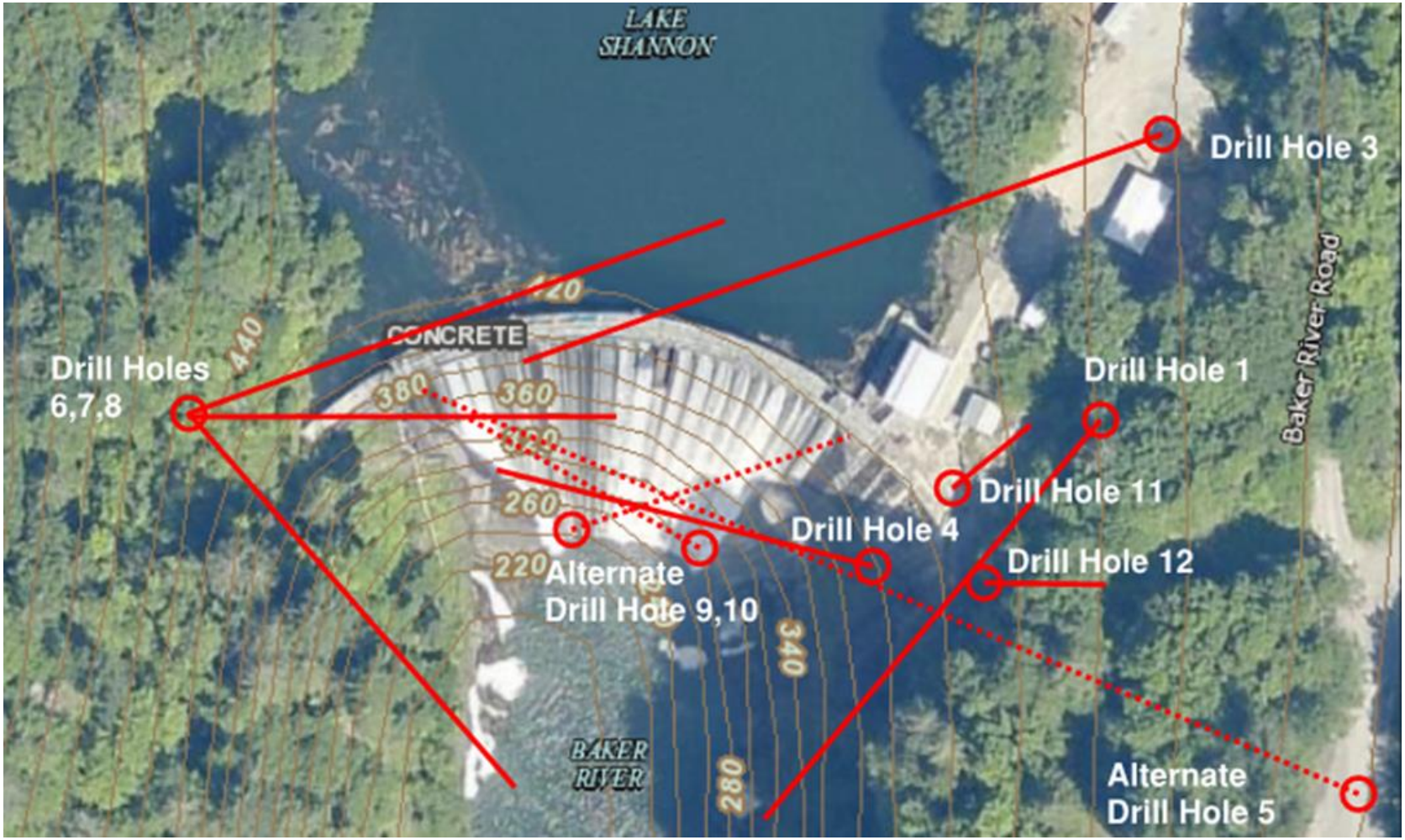
PUGET SOUND ENERGY

2015 Geotechnical Investigations (Currently Underway)

- Additional forebay dye study
- Forebay sub-bottom profiling
- Forebay bottom sediment sampling by vibracore
- Rock core drilling of dam abutments
- Detail core logging
- Borehole investigations and testing
  - Downhole televiewer
  - Packer & dye testing
  - Installation of piezometers

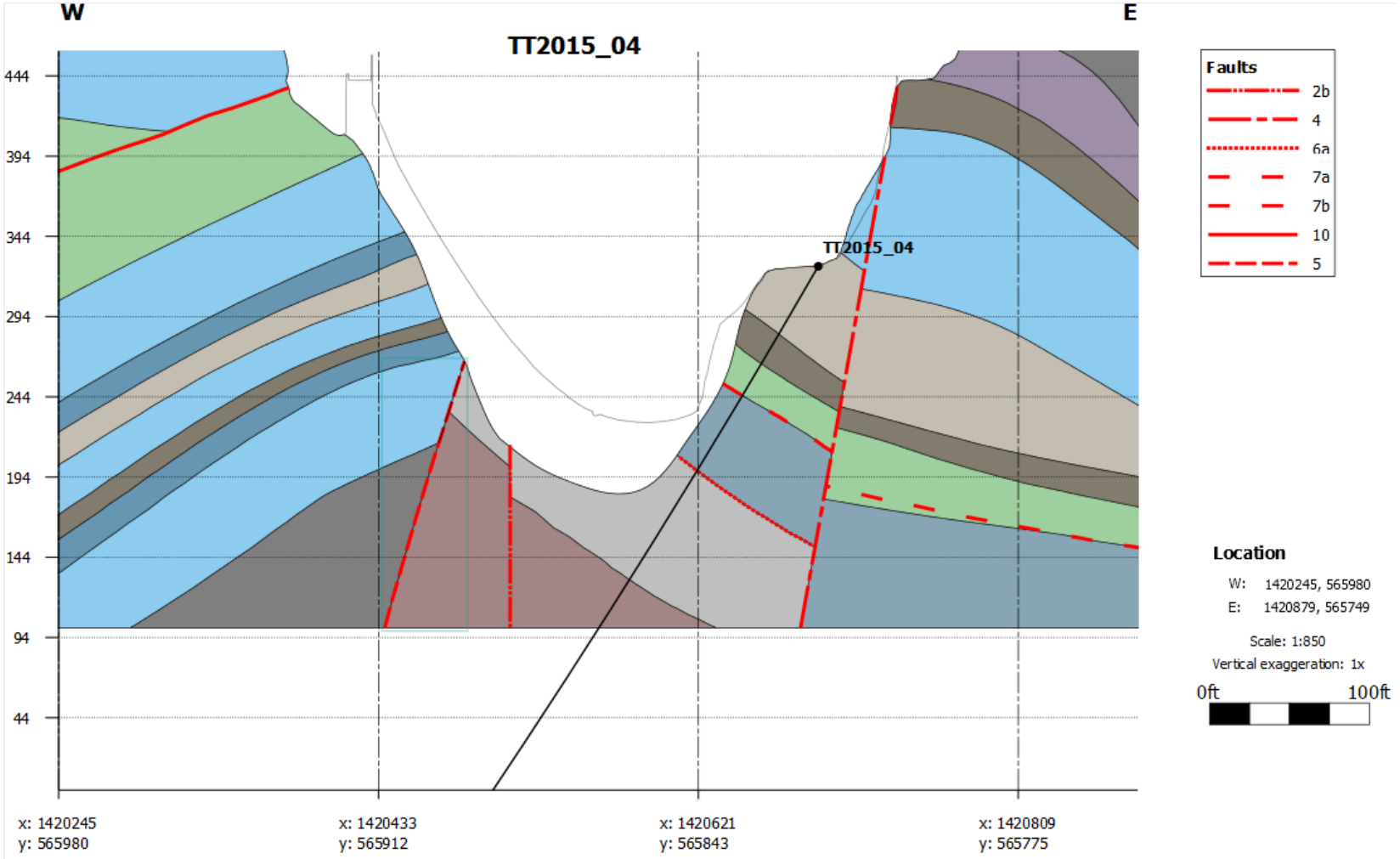
PSE PUGET SOUND ENERGY

2015 Geotechnical Investigations



PUGET SOUND ENERGY

2015 Geotechnical Investigations



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2015 Geotechnical Investigations

Staging Plunge Pool Dye Sensing Equipment

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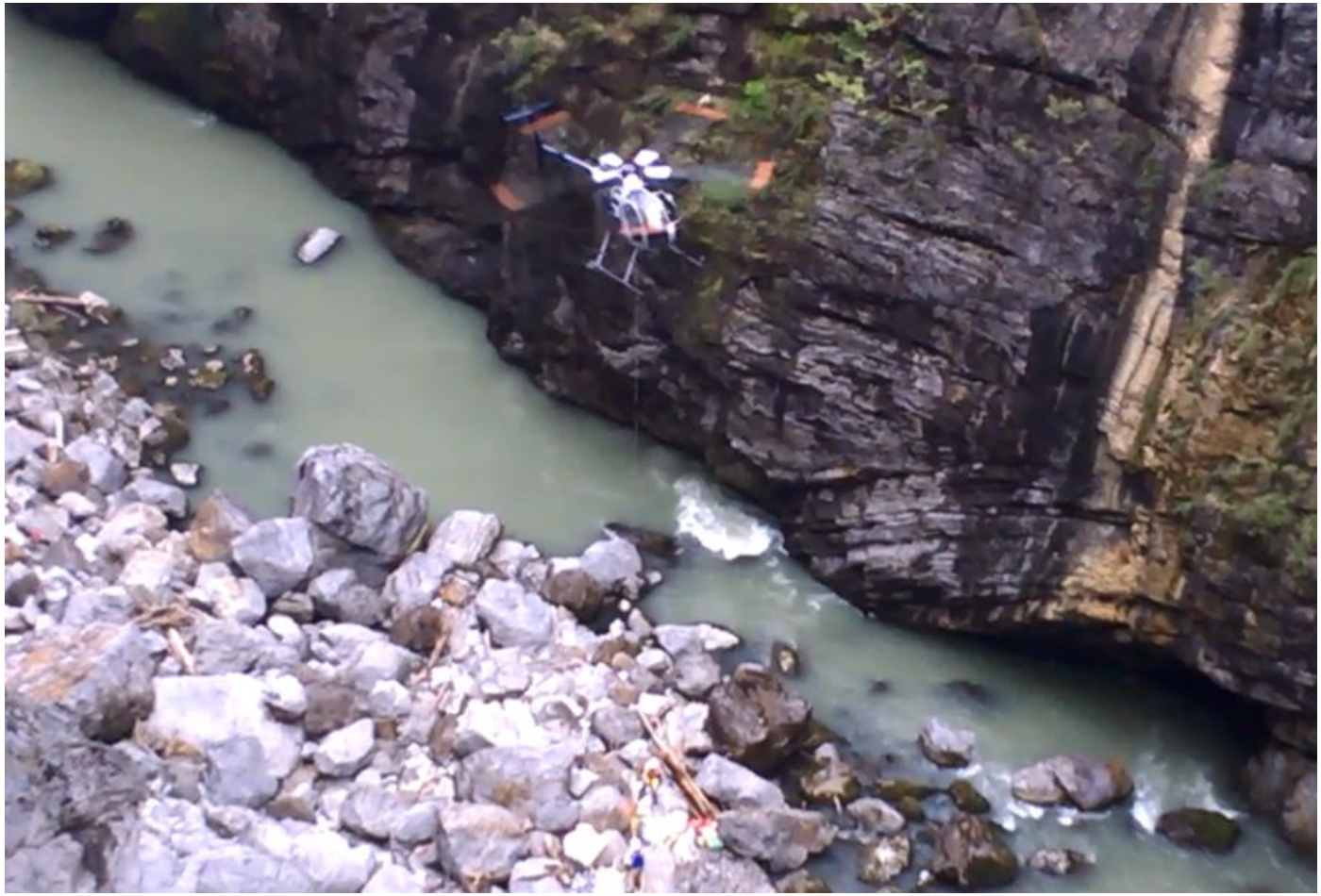
2015 Geotechnical Investigations



Helicopter Flying Equipment Into Plunge Pool

PUGET SOUND ENERGY

2015 Geotechnical Investigations

Plunge pool dye sensors installed

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2015 Geotechnical Investigations

Conducting vibracore sampling of forebay bottom

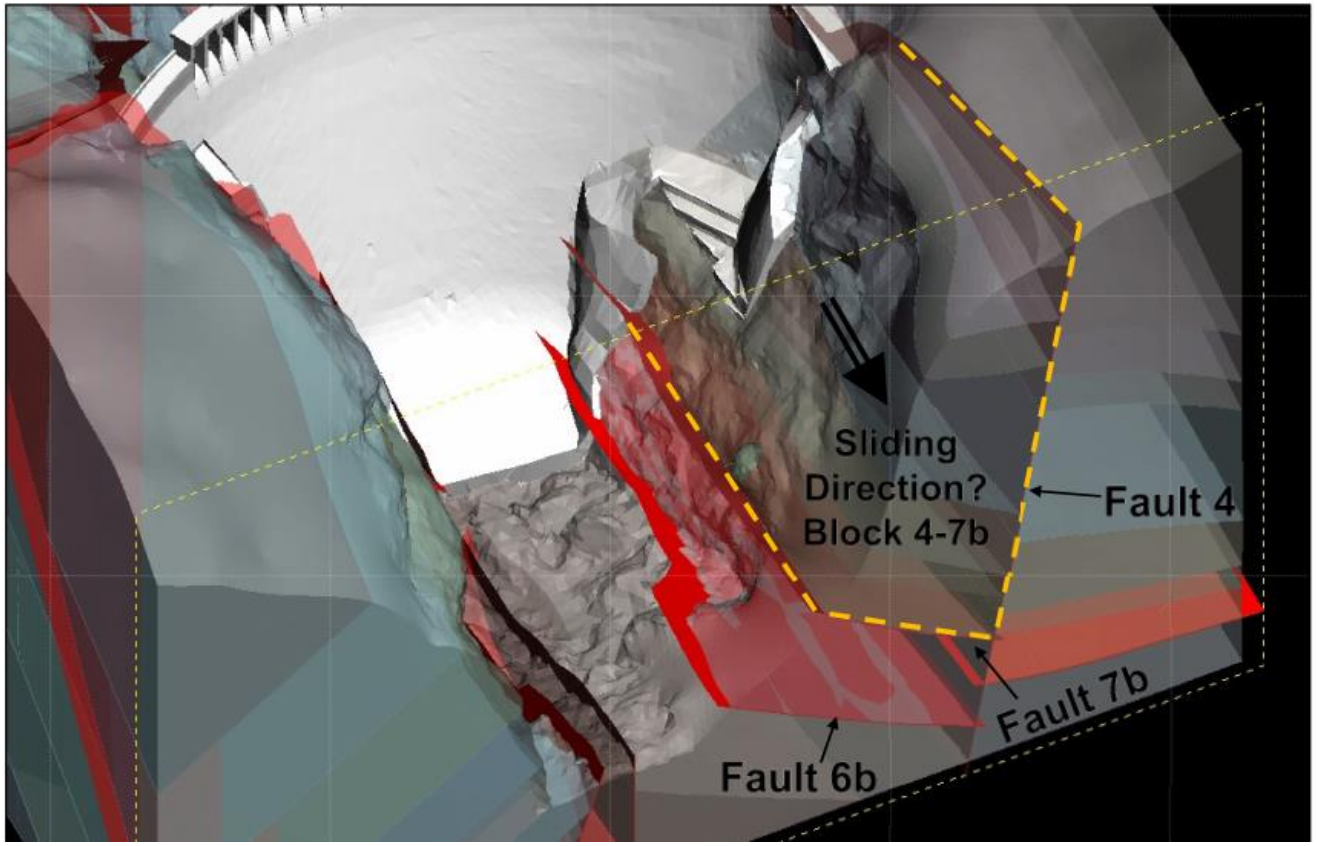
PUGET SOUND ENERGY

2015 Geotechnical Investigations

Core Drill Site on Right Abutment

PUGET SOUND ENERGY

2015 Geotechnical Investigations

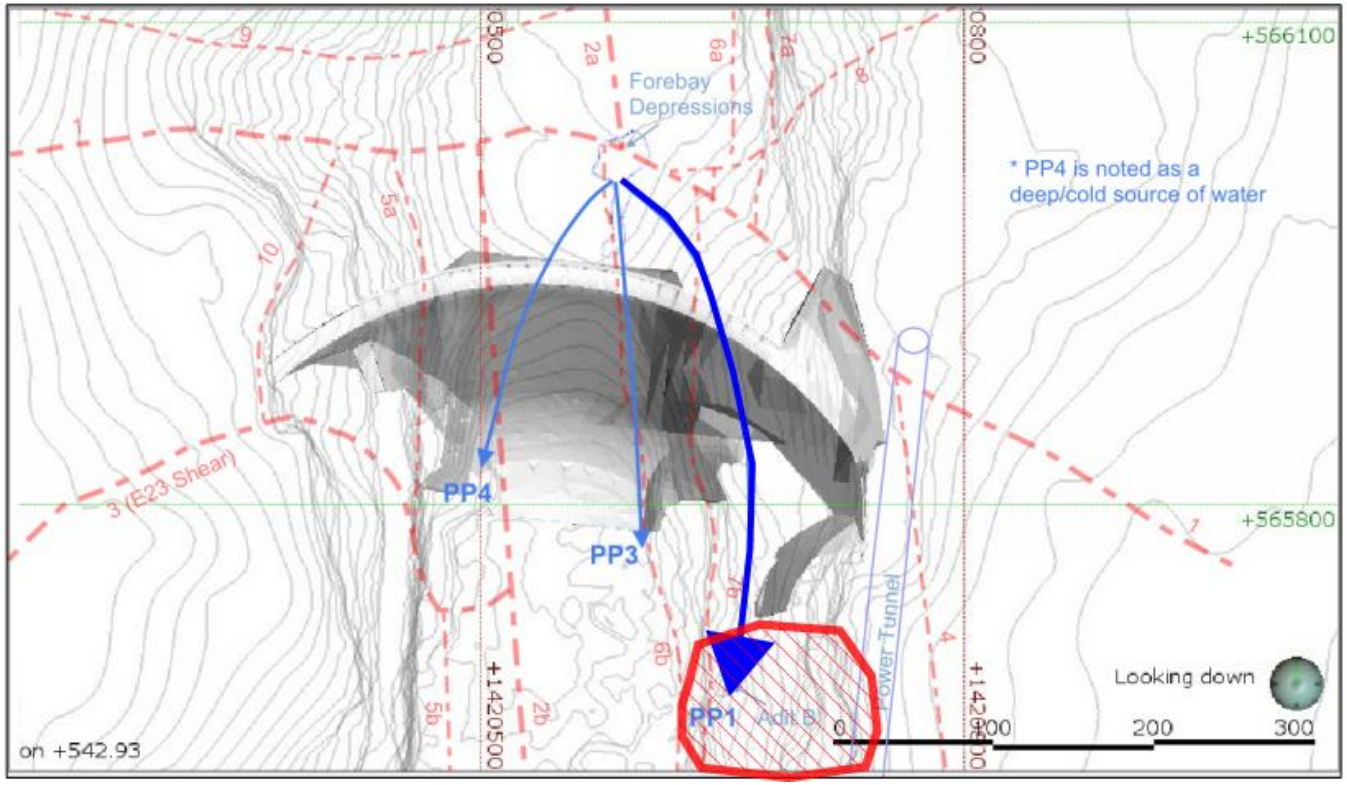


Next Steps Following 2015 Geotechnical Investigations

- Evaluate potential failure modes related to rock abutment stability

PUGET SOUND ENERGY

2015 Geotechnical Investigations



Next Steps Following 2015 Geotechnical Investigations

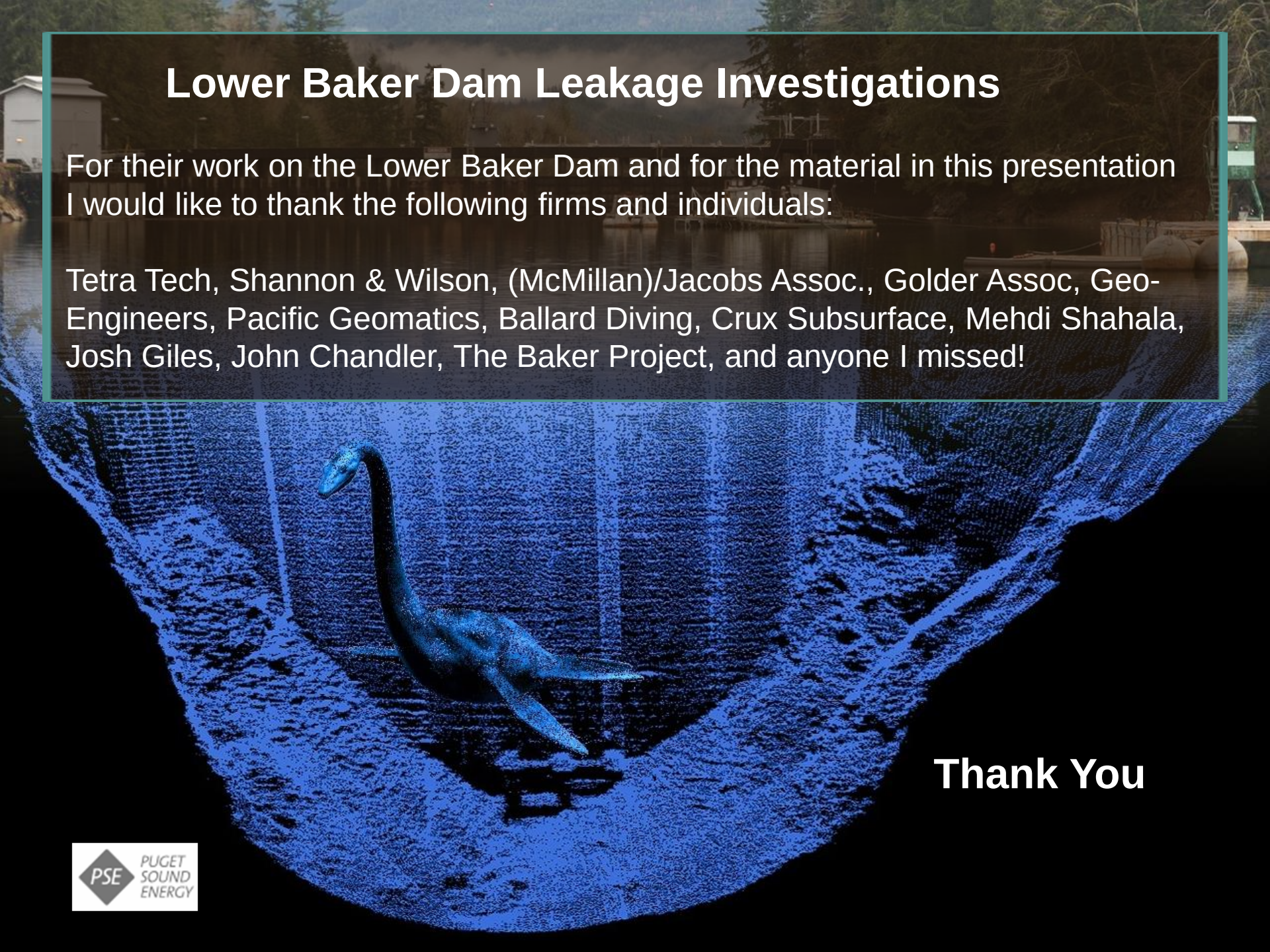
- Determine if the leakage plays a part in potential failure modes
- Identify mitigation if required to reduce potential for dam failure.
- Assess the need to grout the dam

PUGET SOUND ENERGY

Lower Baker Dam Leakage Investigations

For their work on the Lower Baker Dam and for the material in this presentation I would like to thank the following firms and individuals:

Tetra Tech, Shannon & Wilson, (McMillan)/Jacobs Assoc., Golder Assoc, Geo-Engineers, Pacific Geomatics, Ballard Diving, Crux Subsurface, Mehdi Shahala, Josh Giles, John Chandler, The Baker Project, and anyone I missed!



Thank You

PSE PUGET SOUND ENERGY